Site Preparation

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RESPONSE OF SECOND-ROTATION SOUTHERN PINES TO FERTILIZER AND PLANTING ON OLD BEDS—FIFTEENTH-YEAR RESULTS

James D. Haywood and Allan E. Tiarks[1]

Abstract—Two replicated site preparation studies were used to examine the effects of management on loblolly pine (Pinus taeda L.) and slash pine (P. elliottii Engelm. var. elliottii) growth-and-yield in a second rotation on silt loam soils. Treatments included no tillage, flat disking, bedding, and fertilization. After 15 growing seasons of the second rotation in study 1, loblolly pine and slash pine basal area and volume per acre were greater on burned-only plots than on plots mechanically site prepared 38 years earlier. In the first rotation, 15-year-old loblolly and slash pines had averaged 52 and 49 ft tall, respectively; in the second rotation the trees were only 40 and 46 ft tall. In study 2, slash pine responded to 88 lb per acre of phosphorus applied at the beginning of both rotations, but planting on 16-year-old beds had no influence on slash pine growth 15 years later. Cross-rotation comparisons could not be made in study 2 because of age differences when measurements were taken between rotations.

INTRODUCTION

On poorly drained soils in the Southeastern Coastal Plain, pine seedlings have often been planted on beds to improve survival by increasing the volume of unsaturated soil available to roots during rainy periods (Pritchett and Gooding 1975). On west Gulf Coastal Plain silt loam sites where some soils are poorly drained, bedding can be a successful ameliorative treatment if soil depth to the winter water table averages < 1.5 ft (Haywood and others 1990). While the evidence supports bedding on only the most poorly drained sites, bedding is now being used on upland sites in the west gulf region.

Beds are a lasting topographic feature that can disrupt the natural drainage pattern on gently rolling west Gulf Coastal Plain silt loam soils (Haywood 1995). Surface water can pond and adversely affect tree development. Bedding may benefit tree growth through the first five growing seasons only to lose effectiveness by mid- or late-rotation (Derr and Mann 1977; Haywood 1983, 1995). Thus at the end of the rotation, what to do with the beds can be an issue. Should one plant on the old beds, level the site by knocking down the beds, or rework the beds before the next stand of trees is planted?

We studied two sites in central Louisiana to address the issue of whether or not to plant on old beds. At study 1, a second rotation of loblolly pine (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. var. *elliottii*) trees was planted on beds created 22 years earlier (Haywood 1994). On study 2, a second rotation of slash pine trees was planted on beds created 16 years earlier (Tiarks and Haywood 1996). This paper reports on how planting on these old beds influenced growth-and-yield after 15 years of the second rotation. At study 1, we also were able to make 15-year height comparisons between the first and second rotations, but because of age differences when measurements were taken, cross-rotation comparisons could not be made for study 2. Earlier growth comparisons between rotations on one or both sites were made by Haywood (1994), Haywood and Tiarks (1995), and Tiarks and Haywood (1996). Soils and nutritional results for both studies were reported by Tiarks and Haywood (1996).

METHODS

Study Sites

The two study areas are located in Rapides Parish, LA, within 1 mi of each other. Study 1 is on Beauregard (fine-silty, siliceous, thermic Plinthaquic Paleudult) and Caddo (fine-silty, siliceous, thermic Typic Glossaqualf) silt loam soils; study 2 is on predominately Beauregard soil. These soils are acidic, have low natural fertility, can be highly productive with good management, and are common in flatwoods of the west Gulf Coastal Plain (Tiarks and Haywood 1996). The Caddo soil occurs on the lower parts of the level-to-slightly sloping landscape, is poorly drained, and may have a perched water table at or just below the surface during extended periods from December through February (Haywood and others 1990). The Beauregard occurs on slightly higher parts of the landscape, is moderately well drained, and has a winter water table between 1.5 and 2.3 ft. The two soils are very similar in surface horizon characteristics and response to site treatments, including fire and tillage.

On both sites, longleaf pine *(P. palustris* Mill.) and hardwoods were clearcut harvested in the 1920s. After harvesting, a cover of mostly grasses and scattered woody plants was maintained in open range by livestock grazing and periodic burning. Before plot establishment and tree planting, the areas were again cut to reduce woody vegetation.

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Study Establishment

Both studies were established in the 1960s to evaluate disking and bedding as mechanical site preparation methods. Study 1 was established to compare two pine species (loblolly and slash) and three site preparation treatments in a randomized complete block design with four blocks as replicates. Each of the 24 plots (2 pine species times 3 treatments times 4 blocks) measured 144 by 108 ft (0.36 ac). Row spacing was 8 ft, and seedlings were planted 6 ft apart within rows. Measurements were made on the central 10 rows of 10 trees per plot.

Study 2 was established as a randomized complete block split-plot design. There were three main effect site preparation treatments and four blocks as replicates. Only slash pine was planted at study 2. Each of the 12 main plots (3 treatments times 4 blocks) was split into 4 subplots that were 70 by 72 ft (0.12 ac), and to which fertilizer treatments were applied. Row spacing was 10 ft and seedling spacing 6 ft. Tree measurements were made on the center three rows of eight trees per subplot. In both studies, blocking was based on surface drainage.

In study 1, site preparation treatments were: (1) burn-only, all plots were burned in 1960; (2) burn-disk, following burning, some plots were treated with an offset disk harrow once in the fall of 1960 and again in July 1961 to control established grasses; and (3) burn-disk-bed, following burning and disking, technicians created beds averaging 20 in. tall from furrow to crest—before settling—in September 1961 by making two passes with a bedding harrow. The beds were 10 in. tall after 17 years and 8 in. tall after 33 years. The bare-root, 1-0 loblolly and slash pine seedlings were obtained from a Louisiana State nursery. The seedlings were graded and hand planted on the appropriate plots in February 1962. The plots were thinned during the 13th growing season (Haywood 1983) and control burned at least once in the first rotation.

In study 2, the three site preparation treatments were: (1) burned only, (2) disked only, and (3) bedded only. The plots were established in the fall of 1967. The fertilizer treatments applied to one of four subplots in each main plot were: (1) no nutrient amendment, (2) 88 lb per acre of phosphorus (P) as triple superphosphate, (3) 1,000 lb per acre of lime, and (4) a combination of P and lime. The amendments were applied after the burning but before mechanical site preparation so the P and lime were mixed into the soil only on the disked or bedded plots. However, incorporation of P fertilizer is unnecessary on these soils (Shoulders and Tiarks 1980). In February 1969, slash pine seedlings similar in quality to those used in study 1 were hand planted in study 2.

Tiarks and Haywood (1996) outlined all of the treatment applications and dates soil and plant samplings were done for both studies and rotations. In 1983, both studies were clearcut harvested. Logging equipment was not allowed on the plots. After harvest, both study sites were broadcast burned to reduce logging residue and facilitate planting the next year. The disked or bedded plots were not retreated mechanically, so the influence of only the initial site preparation treatments could be evaluated during the second rotation.

In February 1984, the plots on both sites were hand planted with the same species of pine as were planted in the first rotation. Seedlings were obtained from a Louisiana State nursery and were similar in quality and probably better genetically to those used in the first rotation. The seedlings were planted at the original spacing between stumps in the original planting rows.

During the first rotation, grasses were initially the principal competitors with the pine trees, although woody competitors were present at both study sites. During the second rotation, all plots in study 1 were rotary mowed yearly between the rows of pine trees to control the size of woody competitors. Woody vegetation within planted rows was cut down during the eighth growing season. The plots were control burned 10 years after planting.

In study 2, the competition was allowed to change in response to the treatments so no competition control was applied to any of the plots. Where no P had been applied, the competition was mostly grasses in both rotations, but on plots that had received P, the amount of woody competition gradually increased during the first rotation and was much greater in the second.

The lime applied to the first rotation of study 2 had no effect on pine growth (Tiarks 1983), so that treatment was replaced with a nitrogen (N) application of 50 lb per acre applied as ammonium nitrate in the beginning of the eighth growing season of the second rotation. The rate of N was based on pine response to N on nearby Beauregard soils (Shoulders and Tiarks 1983).

Measurements

After 15 growing seasons, total heights were measured with a clinometer, and a diameter tape was used to measure diameter at breast height (d.b.h.). Outside bark total stem volumes were calculated for loblolly (Baldwin and Feduccia 1987) and slash (Lohrey 1985) pines.

Management Effects on Growth Comparisons

At study 1, a thinning of the 13-year-old stands in the first rotation did not affect the total height curve for either species. Therefore, height comparisons could be made between the first and second rotation stands at age 15 years. However, thinning nullified comparing diameter, basal area, or volume differences between rotations after age 10 (Haywood and Tiarks 1995). Nevertheless, pine variables could be compared among treatments at the end of the second rotation.

At study 2, pine beetle (*Dendroctonus* spp. and *Ips* spp.) infestations during the second rotation nullified the usefulness of the diameter, basal area, and volume estimates after age 10 years. Height comparisons between rotations were also not possible past age 10 because of differences in ages when measurements were taken between rotations (Tiarks 1983). However, tree heights could be compared among treatments at the end of the second rotation.

Table 1—For study 1, mean total height, d.b.h., and outside-bark volume and stand density, basal area, and yield for 15-year-old loblolly and slash pines after the second rotation

Pine species and site preparation treatments[a]	Total height	D.b.h.	Volume per tree	Number per acre	Basal area	Total volume
	Feet	*In.*	*Ft³*	*Count*	*Ft²/ac*	*Ft³/ac*
Loblolly pine						
(1) Burn-only	40.1	5.8	4.2	737	144	3,102
(2) Burn-disk	40.2	5.9	4.2	696	136	2,894
(3) Burn-disk-bed	39.4	5.6	3.9	669	122	2,568
Means	39.9	5.8	4.1	701	134	2,855
	Prob > F-value					
Treatments (trt)	.806	.478	.392	.256	.035	.068
Linear contrasts						
Trt 1 vs. trt 2+3	.803	.763	.426	.139	.033	.058
Trt 2 vs. trt 3	.560	.257	.271	.488	.073	.125
Error mean square	3.056	.060	.148	2,717.382	80.375	66,973.974
Slash pine						
(1) Burn-only	45.9	6.2	5.4	635	137	3,402
(2) Burn-disk	45.8	6.3	5.7	556	124	3,067
(3) Burn-disk-bed	45.6	6.1	5.1	585	119	2,912
Means	45.7	6.2	5.4	592	127	3,127
	Prob > F-value					
Treatments (trt)	.959	.682	.723	.549	.029	.017
Linear contrasts						
Trt 1 vs. trt 2+3	.838	.927	1.000	.325	.012	.008
Trt 2 vs. trt 3	.851	.404	.440	.687	.356	.247
Error mean square	2.493	.202	1.050	9,718.988	50.174	29,138.913
Combined species analysis						
	Prob > F-value					
Species	< .001	.012	.001	.004	.060	.020
Treatments (trt)	.837	.402	.478	.246	.001	.004
Linear contrasts						
Trt 1 vs. trt 2+3	.770	.948	.767	.099	.001	.003
Trt 2 vs. trt 3	.610	.185	.245	.977	.048	.078
Species times trt interaction	.959	.956	.899	.764	.615	.787
Error mean square	3.549	.131	.591	6,123.717	75.993	64,910.527

[a] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

Table 2—For study 1, comparison of total height between the first and second rotations for 15-year-old loblolly and slash pine

Rotations and site preparation treatments[a]	Total height: Loblolly pine	Total height: Slash pine
	- - - - - - - - - Feet - - - - - - - - -	
First rotation		
(1) Burn-only	50.6	48.7
(2) Burn-disk	53.4	48.6
(3) Burn-disk-bed	52.6	50.4
Second rotation		
(1) Burn-only	40.1	45.9
(2) Burn-disk	40.2	45.8
(3) Burn-disk-bed	39.4	45.5
	Prob > F-value	
Rotation	< .001	.007
Main effect error mean square	3.034	1.690
Treatment	.217	.673
Rotation times treatment interactions	.184	.459
Subplot effect error mean square	2.419	3.126

[a] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

Data Analysis

For study 1, treatment and species comparisons for per pine d.b.h., height, and volume, as well as stand stocking, basal area, and yield after the second rotation were made by analyses of variance using randomized complete block design models (a = 0.05) (Steel and Torrie 1980). Fifteenth year height comparisons were made between the two rotations by analysis of variance using a split-plot-in-time model with rotation as the main plot effect and site preparation as the subplot effect (Haywood and Tiarks 1995). For study 2, pine height results were analyzed by a split-plot randomized complete block design model with site preparation as the main plot and P and N fertilization as the subplot effects (a = 0.05) (Steel and Torrie 1980). We also report probabilities > F-value (Prob) of over 5 percent but < 15 percent because natural variation is always an issue in field studies regardless of the care taken to reduce it (Peterman 1990, Thomas 1997) and this added information may be of interest to the reader.

RESULTS

In study 1, 15-year-old loblolly pine basal area per acre was significantly greater on the burned-only plots (144 ft^2 per acre) than on the two mechanical treatments (129 ft^2 per acre) (table 1). Yield was greater on the burned-only plots (3,102 ft^3 per acre) than on the two mechanical treatments (2,731 ft^3 per acre) at Prob = 0.06. Bedding as a secondary treatment following flat disking further reduced loblolly pine basal area (122 ft^2 per acre) and volume (2,568 ft^3 per acre) compared to flat disking alone (136 ft^2 per acre and 2,894 ft^3 per acre) at Prob = 0.07 and 0.12, respectively.

Fifteen-year-old slash pine basal area and yield were both significantly greater on the burned-only plots (137 ft^2 per acre and 3,402 ft^3 per acre) than on the two mechanical treatments (122 ft^2 per acre and 2,989 ft^3 per acre) (table 1). There were no important differences in slash pine growth-and-yield between the two mechanical treatments.

When the two pine species were compared, the 15-year-old slash pine had significantly greater total height, d.b.h., and volume per tree than loblolly pine after two rotations (table 1). There were significantly fewer slash pine than loblolly pine, but the slash pine stands (3,127 ft^3 per acre) still had greater yields than the loblolly pine stands (2,855 ft^3 per acre).

When site treatments were compared with both pine species in the analyses, basal area and yield were both significantly greater on the burned-only plots (141 ft^2 per acre and 3,252 ft^3 per acre) than on the two mechanical treatments (125 ft^2 per acre and 2,860 ft^3 per acre) (table 1). Bedding after flat disking significantly reduced pine basal area (121 ft^2 per acre) compared to flat disking alone (130 ft^2 per acre). It also resulted in less yield (2,740 ft^3 per acre) when compared to flat disking (2,981 ft^3 per acre) at Prob =

Table 3—For study 2, comparison of total height of 15-year-old slash pine after the second rotation

Site preparation treatments	P	N[a]	Total height
	- - *Lb/ac* - -		*Feet*
(1) Burn-only[b]	0	0	50.0
	0	50	48.6
	88	0	53.3
	88	50	54.2
(2) Burn-disk[b]	0	0	46.2
	0	50	47.3
	88	0	51.9
	88	50	48.8
(3) Burn-bed[b]	0	0	47.3
	0	50	44.1
	88	0	48.8
	88	50	49.4
			Prob > F-value
Treatment			.284
Main effect error mean square			46.053
Phosphorus			< .001
Nitrogen			.278
Phosphorus times nitrogen interaction			.681
Treatment times phosphorus interaction			.833
Treatment times nitrogen interaction			.834
Subplot error mean square			7.127

[a] Lime was applied at 1,000 lb per acre in the first rotation only. The N fertilizer treatment was applied only in the second rotation at the beginning of the eighth growing season.

[b] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

0.08. There were no significant species-by-treatment interactions.

Both pine species were significantly taller in the first rotation (table 2), as reported at younger ages by Haywood (1994) and Haywood and Tiarks (1995). Loblolly and slash pines averaged 52 and 49 ft tall in the first rotation and 40 and 46 ft tall in the second, respectively. There were no rotation-by-treatment interactions.

In study 2, P fertilization significantly increased slash pine total height. The fertilized 15-year-old slash pines averaged 51 ft and the unfertilized pines averaged 47 ft (table 3). Nitrogen fertilization and mechanical site preparation did not significantly influence slash pine total height. There were no significant interactions.

DISCUSSION

At study 1, mechanical site preparation in the early 1960s adversely affected loblolly and slash pine basal area and yields 38 years later, and planting on old beds also adversely affected the productivity of loblolly pine but not slash pine. At study 2, slash pine was also not adversely affected by planting on old beds.

Interestingly, loblolly pine is more responsive to planting on newly created beds than slash pine on silt loam soils in the west Gulf Coastal Plain (Haywood and others 1990). Perhaps as the beds become smaller due to erosion of the crown and filling of the furrow, loblolly pine no longer enjoys the benefit of better drained soil for root growth compared to flat areas, although the negative effects of bedding on surface drainage remain (Haywood 1995). These effects may limit loblolly pine growth more than slash pine growth (Haywood and others 1990).

Also, where pine roots tended to concentrate in the beds, the trees might have drawn down nutrient reserves during the first rotation. On silt loam soils in the west Gulf Coastal Plain, loblolly pine is more sensitive to P deficiencies than slash pine (Tiarks and Shoulders 1982). A differential reduction in nutrients in the beds versus the flat areas may partly explain why loblolly pine did less well on old beds than slash pine.

Loblolly pine was somewhat more productive than slash pine at the end of the first rotation at study 1 (Haywood 1983), but the opposite was true in the second rotation (table 1). Indeed, we report a general decline in height growth for both pine species in the second rotation at study 1. Because loblolly pine needs more P on poorly drained soils than slash pine (Tiarks and Shoulders 1982), and as P is lost in harvesting and burning, a more severe growth decline occurs for loblolly pine than for slash pine (Haywood and Tiarks 1995). Planting on old beds worsens this.

Fertilization is a way to improve growth or to overcome nutrition deficiencies on Paleudult soils (Haywood and Tiarks 1990, Jokela and others 2000) and at study 2, P fertilization significantly increased slash pine yields in the first rotation (Tiarks 1983) as well as total height in the second rotation (table 3). Based on these results, we recommend P be applied to Paleudult soils at the beginning or early in the rotation on intensively managed southern pine plantation sites. Bedding is not recommended on somewhat poorly drained and better drained sites because it is usually ineffective and can create long-term management problems (Derr and Mann 1977, Haywood 1995, Haywood and others 1990). Where old beds are found, they should be either leveled or recreated and P fertilizer applied before planting loblolly pine.

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LOBLOLLY PINE GROWTH 13 YEARS AFTER FOUR SITE PREPARATION TREATMENTS

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Abstract—Thirteen-year growth results of 1-0 planted loblolly pine seedlings (*Pinus taeda* L.) on differently prepared upland mixed pine-hardwood sites located in north western Louisiana are presented. The study was designed as a randomized complete block consisting of three blocks of four site preparation treatments, which included: chop and burn, windrow, fuelwood harvest, and fuelwood harvest followed by an application of herbicide. Thirteen-year-growth results of the planted pine show no significant height differences but highly significant diameter differences ($P < 0.01$). Mean height varied from 40 feet for the fuelwood treatment to maximum of 43 feet for the windrow treatment. Mean diameter varied from 5.3 for the fuelwood and the fuelwood/herbicide treatments to a maximum of 6.9 inches for the chop and burn site preparation treatments which was significantly different. The initial performance of the stands change over time and the potential gains by using herbicides to control hardwoods and by using genetically improved seedlings was lost because of high plantation density and pine on pine competition.

INTRODUCTION

In 1984 a study was initiated to evaluate the effects of four site preparation treatments on the soil chemical and physical properties and on the influence of competing vegetation on initial loblolly pine growth. The treatments were chop and burn (CB), windrow (WR), fuelwood harvest (FW), and fuelwood harvest followed by an application of two gallons per acre of Garlon herbicide (FW/H). The early results of the treatments on soil variables and pine growth were reported by Slay and others (1987), Slay and others (1987b) and Lockaby and others (1988), and generally reinforced conventional wisdom about these site preparation methods. The treatments with the most traffic such as the pile and windrow had the most compaction followed by the chop and burn. The fuelwood had the most competing vegetation whereas fuelwood/herbicide had the least competing vegetation. The concentrations of potassium, calcium, magnesium, and organic matter generally followed the pattern of the vegetation (fuelwood > chop and burn = windrow > fuelwood/herbicide).

During the last 15 years there has been an evolution of site preparation techniques. The use of the pile and windrow and chop and burn are out of favor and are rarely used today in this region. Fuelwood harvests, as was done in this study, are also rarely done. However, intensive utilization of the material in our forest sites resembles this technique. The use of herbicide to control woody vegetation was in its infancy, and in the time since the application of this treatment in this study, new herbicides and application techniques have been developed and employed. Since several of these site preparation techniques used 15 years ago are no longer considered the technique of choice, why then should we look at this older study? The purpose of this study is to revisit a 15-year-old study site to see if the early growth results had been sustained to the first thinning and determine effectiveness of various site treatments in producing wood. Also, if there were differences in production patterns at age 14 from the one and the three-year growth results, an attempt to explain the deviation from the expected and actual measured juvenile growth performance was made.

METHODS

The study area, located in northwest Louisiana, is characterized by a warm and humid climate. The themic temperature regime features a mean annual range from 59-72°F, and average precipitation is 56 inches per year (Newton 1972). Two soil series occur throughout the area. The Gore series, a Vertic Paleudalf, composes 0-75 percent of the site; the remaining 25-35 percent consists of the Kolin series, a Haplic Glossudalf. These soils are associated with secondary terraces of the Red River. The site is homogeneous with respect to soil texture, slope and aspect. Slope ranges from 1-5 percent.

During the summer of 1983 a stand of loblolly pine approximately 40 years old was removed from the site. In the summer of 1984 four site-preparation treatments were arranged in a randomized complete block design consisting of three blocks. The treatments were chop and burn (CB), windrow (WR), fuelwood harvest (FW), and fuelwood harvest followed by an application of two gallons per acre of Garlon 4 herbicide (FW/H). The fuelwood harvest is equivalent to a whole-tree chipping operation and was sometimes used in lieu of site preparation during this period. The CB treatment consisted of a single pass with a drum chopper (pulled by a bulldozer) followed by a broadcast burn. The WR treatment was composed of a shearing

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Table 1—Third year ground line diameter and height of loblolly pine saplings planted on four different site preparation treatments

Treatment	Ground line Diameter	Total Height
	in	ft
Fuelwood/ Herbicide	2.4a	9.6a
Chop&burn	2.1b	8.6b
Windrow	1.8c	8.4b
Fuelwood	1.7c	8.1b

Means followed by the same letter are not significantly different at the $P < 0.05$ probability level.

operation combined with piling of sheared material into windrows. The windrow piles were outside the treatment areas, thus the treatment plots where not affected by the debris pile nor increased nutrient levels that may result from concentrations of displaced soil and pile and burned biomass. All site preparation treatments were done during the first week of July 1984. All plots were planted (6x8 foot spacing) the following winter (January 1985) with 1-0 loblolly pine seedlings genetically selected for this site. Treatment plots were one acre in size and the measurement plots were 1/10 acre and located in the center of each treatment plot.

In 1989 the site was revisited to see if the initial growth results were still as they were after the first year, and to evaluate the competing vegetation on the different site preparations. Trees within the 1/10-acre measurement plots were measured for diameter (ground line) and height, and within each measurement plot, samples of herbaceous and woody competing vegetation were taken from three randomly placed 1/1000-acre sample plots. Plant samples were oven-dried and weighed.

In September 1999 the 1/10 acre measurement plots were measured for height and diameter (DBH). Volume was calculated using the formula $0.002678D^2 H$ (Baldwin and Feduccia 1991). Analysis of variance (SAS 1985) was conducted to determine significance and Duncan's multiple range test was used to separate the means.

RESULTS AND DISCUSSION

The measurements in 1989 showed the same general pattern as the first year results reported by (Lockaby 1988). The first year results for diameter (GLD) were ranked FW/H = CB = WR > FW with the FW significantly ($P < 0.05$) smaller. The height was not significantly different. The three year results were ranked FW/H > CB > WR = FW with the fuelwood with herbicide treatment significantly ($P < 0.05$) larger in GLD and in height (table 1).

The measurements at year 14 (1999) showed a marked change in the ranking for diameter (DBH). The ranking was CB = WR > FW = FW/H or a complete change from what was the best initial performing treatment/seedling combination (FW/H) to being the worst. The CB and WR treatments were significantly ($P < 0.05$) different from the fuelwood and fuelwood with herbicide. There was no difference in total height (table 2).

When the 1999 measurements were being planned and the earlier work reviewed, the assumption was made that the fuelwood with herbicide would be the most effective treatment because of the initial control of competing hardwood vegetation and the past early seedling performance on these sites. However, this was not the case and in the interim the other site preparation treatments were, over the last 10 years, more effective from a diameter standpoint, and the fuelwood with herbicide was ranked last and significantly smaller in diameter than the other treatments.

When measurements at age three were taken, the herbaceous and woody biomasses were also sampled. At that time there was no difference in herbaceous material between the treatment plots. Woody biomass (hardwood sprouts) was significantly less ($P < 0.05$) in the WR treatment plots but the other site preparation treatments had the same woody competition. This was a change from the first year results (Lockaby and others 1988) where the fuelwood with herbicide plots had considerably less competing woody material with the other treatments statistically the same. Although this change in competing woody material had occurred by the end of the third growing season, it was not reflected in the total growth measured in each treatment. However, between year three and fourteen the effect of the herbicide was gone and the growth pattern of other treatments including the FW with no additional site work (essentially a check) were as good or better than the FW/H site preparation. The two older, more traditional site

Table 2—Fourteen-year diameter (DBH) and height of loblolly pine trees planted on four different site preparation treatments

Treatment	DBH	Total Height	Volume Per Tree
	in	ft	cuft
Chop&Burn	5.8	41.5	4.0a
Windrow	5.6a	41.0a	3.7a
Fuelwood	5.3b	41.0a	3.4bc
Fuelwood/ Herbicide	5.3b	40.5a	3.2c

Means followed by the same letter are not significantly different at the P < 0.05 probability level.

preparation treatments (WR and CB) had produced the largest diameters. The total height was the same across the treatments.

Historically, looking at the development of this stand there are two reasons that may explain why the seedlings given the early advantage of freedom from competition did not maintain this advantage. They are planted pine seedling numbers and planted pine domination of the site.

The stand was planted on a 6X8 spacing (Slay 1986), which is 908 seedlings per acre. These seedlings were genetically improved, and family mixes tested to perform well on the soil types at the planting site were used. The survival was 94 percent at the end of the first year or 850 trees per acre. At age three the survival was essentially unchanged. After age three the crowns began to close and competition became more and more intense with each additional years growth. The close spacing, high survival and fast growth of the planted pine completely dominated the stands with little but planted pine remaining when year 14 measurements were made. Wild pine seedlings and hardwood observed in the early years of the stand were in the overtopped position and essentially were not a factor in the stand.

The planted pine spacing is another matter. The planted pine on planted pine competition has been very intense in the treatment stands. Early fast growth and crown closure negated any advantage of one site treatment over the other. When the 14 year measurements where taken, there were still 762 trees per acre and any advantages given early by cultural treatments or by the use of genetically superior planting stock were lost in the competition among high populations of planted trees. The trees in the treatments having the best early results quickly closed canopy and slowed growth allowing the other treatments to catch up and in some cases exceed the total growth after 14 years. At age 14 the trees in all treatments plots were in less than desirable physical condition based on observations of crown percent and general fullness of the crown indicating severe competition for several years.

The lesson to be learned from this study is that the advantages of using cultural practices and improved genetic planting stock can be quickly diminished by the presence of large seedling/sapling/tree numbers. Trends that appear to be positive initially may not be maintained with high numbers of trees. Adjustment of tree numbers at planting or early in the rotation of the stand is important to keep the stand growing at its potentional. Ignoring this can, as is the case in this study, reduce severely the potential of an adequate or any return on a cultural or genetic investment. This study may be unusual in that the survival was very high but it indicates the importance of control of competition not only from hardwoods or wild pine but control of competition of the trees that we plant. Without being relatively "free to grow", investments early in the stand life may be ineffective.

ACKNOWLEDGMENTS

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HEIGHT RESPONSE TO HARVESTING INTENSITY AND SITE PREPARATION IN FOUR YOUNG LOBLOLLY PINE PLANTATIONS

Thomas J. Dean and Ray A. Newbold[1]

Abstract—A study was conducted to analyze the general effects of harvesting intensity and postharvest treatments on the average, three-year height of loblolly pine (*Pinus taeda* L.). This was accomplished by analyzing treatment effects across four study sites by treating the locations as random effects in the statistical model. Whole-tree harvesting using conventional methods had no distinguishable effect on the three-year average height. The main effect of bedding on height was not significant, but within the hand-felled harvest treatment, it significantly reduced height growth 0.12 meter. Herbaceous weed control increased three-year average height by 0.26 meter, and its effect on height was greater when the previous stand was harvested by conventional methods. Fertilization was the only treatment that increased three-year average height and did not interact with harvesting intensity. Across both harvesting treatments, fertilization increased three-year average height by 0.36 meter. Based on this analysis, effects observed here should be applicable to other similar sites across the Southeast.

INTRODUCTION

A study was initiated in 1993 to evaluate the impacts of the compaction and biomass removal associated with timber harvesting on the growth of the next plantation planted on that site. One of the goals of this study named Cooperative Research in Sustainable Silviculture and Soil Productivity, or CRiSSSP for short, is to evaluate this impact in as near of an operational setting as can be achieved while maintaining statistical control of treatments. Consequently, compaction as a treatment effect is the increase in bulk density and soil strength that harvesting equipment produced while moving across the site, and biomass removal as a treatment effect is the biomass intentionally or unintentionally moved from the site during harvesting. The actual treatments in this study are conventional, whole-tree harvesting with saw shears and grapple skidders and hand felling and lifting out only the merchantable portion of the stem. The movement of harvesting equipment across the site and the different removal restrictions produced differences in soil compaction and biomass removal that were measured after the harvest. This study contrasts the USDA Forest Service Long-term Study where compaction and biomass removal are directly and quantitatively manipulated (Powers and Avers 1995). Site preparation practices are included in this study to investigate their impact on growth, their role in correcting detrimental harvesting impacts, as well as their possible interaction with harvesting intensity.

This basic study has been replicated on four sites across the southeastern United States (table 1), and tree height has been measured annually for at least three years at each location. This creates the opportunity to evaluate the general impact of harvesting intensity and site preparation on early growth of newly established loblolly pine (*Pinus taeda* L.) plantations. By treating the various sites as random locations, any of these treatments that produce a change in height is evidence that the effect would occur at any random location across the Southeast. The objective of this paper is to determine whether general statements are possible concerning the effect of harvesting intensity, bedding, fertilization, and herbaceous weed control within the first three-years of height growth in loblolly pine plantations in the Southeast.

METHODS

At each study location, harvest intensity is factorially combined with bedding, fertilization, and herbaceous weed control. The combinations with the site preparation and early cultural treatments is incomplete because not all of the postharvest treatments were applied at each location. Each postharvest treatment was used at two locations at a minimum, however (table 2). Each study location was blocked according to soil type and drainage, and the treatments randomly assigned to 14 x 14 tree plots, each covering approximately 0.15 hectare. Three years of annual height measurement on 100 trees within each plot and location were analyzed using a linear model that mixed fixed and random effects (Littell and others 1966). The study locations and blocks within locations were considered random.

Exact postharvest treatment protocols varied by location. Complete descriptions are given by Wang and others (in press). Each site received an aerial application of imazapyr mixed with either triclopyr or glyphosate for minimum competition control. Bedding was performed with a single pass of two 85-centimeter disc pulled behind a tractor. Herbaceous weed control consisted of spraying a mixture of imazapyr and sulfometuron in a 1.2-meter band over the top of the seedlings. Fertilization consisted of either broadcast application of diammonium phosphate at 250

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Table 1—Locations and characteristics of study sites (all sites have a mean July temperature of 27°C)

Location	soil series	soil subgroup	Average Rainfall (mm)
Fred, TX	Kirbyville	Oxyaquic Paleudult	1360
Bryceland, LA	Mahan	Typic Hapludult	1370
Pine Grove, LA	Toula	Typic Fragiudult	1680
Bainbridge, GA	Hornsville	Aquic Hapludult	1670

kilogram/hectare or a complete fertilizer with micronutrients banded around each seedling. All seedlings were hand planted.

RESULTS AND DISCUSSION

Analysis was performed on all main effects and selected interactions in order to obtain interpretable results. The only treatment that did not interact with harvest intensity was fertilization (table 3). During the first three years of growth after treatment, fertilization significantly increased height growth by an average of 0.36 meter.

Both bedding and herbaceous weed control interacted with harvest intensity in their effects on average, three-year height. Bedding caused a significant reduction in height where the previous stand was hand-felled and removed by lifting the boles from the plot, and it had no effect on the average, three-year height where the previous stand was harvested by conventional means (figure 1a). The negative effect of bedding on height in the hand-felled plots was probably due to debris that was incorporated into the beds. During dry summers, this would reduce the moisture holding capacity of the beds as well as tree growth. With little or no debris in the beds, tree growth was unaffected.

Table 2—Distribution of treatments between study sites

Location / Treatment	Fred TX	Bryceland LA	Pine Grove LA	Bainbridge GA
Harvest intensity	X	X	X	X
Fertilization	X			X
Bedding	X		X	
Herbaceous weed control	X	X	X	

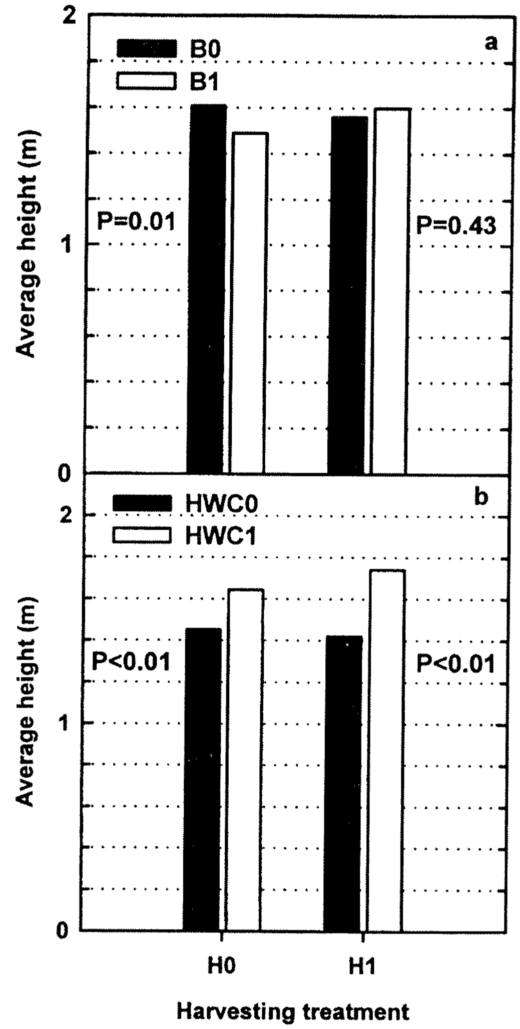

Figure 1—Interaction of harvesting intensity with bedding (a) and with herbaceous weed control (b) on three-year average height. B0 and B1 are not bedded and bedded; HWC0 and HWC1 are not sprayed for herbaceous weed control and sprayed; and H0 and H1 are hand-felled boles only harvesting and conventional, whole-tree harvesting, respectively. P values are for bedding or herbaceous weed control effects within specific harvesting treatments.

Table 3—Statistical summary of treatment effects and selected interactions

Effect	F value	Prob > F
Harvest (H)	0.21	0.64
Fertilization (F)	82 .0	<0.01
Bedding (B)	1.35	0.25
Herbaceous weed control (HWC)	48.2	<0.01
H x F	0.59	0.44
H x B	5.89	0.02
H x HWC	3.17	0.08

Herbaceous weed control significantly increased the average, three-year height in both types of harvest. The significant interaction occurred because the difference in height due to herbaceous weed control was greater when conventional harvesting methods were used than when the stand was harvested using minimum impact techniques. The slight reduction in height that seemed to occur when the stand was harvested with conventional methods with no postharvest control of herbaceous weeds was more than compensated when plots were sprayed for herbaceous weed control.

CONCLUSIONS

These results indicate that the impacts of conventional, whole-tree harvesting do not cause deleterious effects on average height over the first three years of growth on sites similar to those used in this study. Early fertilization results in significant increases of 0.36 meter in average, three-year height. Bedding significantly reduced height when the previous stand was hand felled and had no significant effect on height after harvesting with conventional means. Herbaceous weed control significantly increased the average height growth over three years, and its effect was greater when the previous stand was harvested by conventional methods. By treating the different locations as random effects in the analysis, the results seen here would apply to sites that are similar to the site used in this study.

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DISTRIBUTION OF SLASH AND LITTER AFTER WET- AND DRY-SITE HARVESTING OF LOBLOLLY PINE PLANTATIONS

Mark H. Eisenbies, James A. Burger, Yi-Jun Xu, and Steve Patterson[1]

Abstract—Displacement of logging slash and forest floor litter in the process of harvesting can interfere with forest nutrient cycling and can modify soil climate in ways that could affect regeneration success and forest productivity. The objective of this study was to assess a visual method for estimating organic matter and slash biomass residues following a typical feller-buncher/grapple-skidder clearcut harvest. A 20 by 20 meter grid was established in six 20-year-old loblolly pine plantations, each of which was 3.2 ha in size. Pre-harvest biomass was estimated using biomass equations developed by Baldwin (1987). Post harvest slash and litter biomass remaining was measured across the grid network by making visual estimates of percent coverage for each of 4 size classes and relating that to biomass using simple linear regression. Harvest slash and litter were collected from 4 m^2 plots and weighed to estimated biomass as a function of percent cover for each size class. Heavy slash (> 2.5 cm) on the wet harvest sites had a biomass of 2.49 kg/m^2, compared to 1.89 kg/m^2 on the dry harvest sites. The amount of light slash (< 2.5 cm) was also significantly greater on the wet harvest sites, 2.47 kg/m^2, compared to that on the dry-harvested sites at 1.99 kg/m^2. Litter biomass, ~2.4 kg/ m^2, and piles, 0.7 kg/m^2, were not significantly different between sites. Visual estimation procedures provide a rough but useful estimate of biomass remaining after harvest (R^2 = 0.42 to 0.67), an extensive spatial estimate that is difficult to ascertain in any other way. The method reveals a certain amount of homogenization after harvesting. Harvesting sites when dry compared to wet results in a larger amount of displacement from the interior of a logging site. These estimates can be used to judge whether harvesting disturbance on organic residues affects stand productivity.

INTRODUCTION

The importance of maintaining site quality and productivity on intensively managed forests is important because a higher production per land unit is needed to satisfy increasing population demands for forest products. Understanding how the forest sites resist, respond to, and recover from disturbances associated with forest management practices is essential for sustaining long-term productivity.

The benefits of organic matter in soils for crop production is well known. It helps synchronize the supply and demand of various plant essential nutrients (Walle and Sims, 1999; Gressel and others, 1996), and it has a positive influence on soil water retention, hydraulic conductivity, and infiltration (Prichett and Fisher, 1987). Soil strength, structure, and morphology are also greatly affected by the amount of organic matter in the soil, which helps to bind soil particles together to form soil aggregates (Mankin et.al., 1996).

Forest management can greatly influence the amount of organic materials remaining on a forest site, and, conversely, soil organic matter will influence the response of sites to management disturbances (Sanchez, 2001; Fearnside, 1999; Dick and others, 1991; Nambiar, 1996). Therefore, it is important to understand how forest practices affect the distribution of harvest slash and litter. The purpose of this study is to evaluate a post-harvest visual biomass inventory method based on Terry and Chilingar (1955), and to compare how two harvesting methods, dry-weather and wet-weather harvesting, affects spatial distribution of organic matter.

MATERIALS AND METHODS

The study site is located near Cottageville, SC, on the Atlantic coastal plain of South Carolina. The topography is flat to gently rolling; soil parent material consists of marine and fluvial sediments deposited during the Oligocene and Pleistocene eras (Stuck, 1982). Soils are poorly to somewhat poorly drained and have an aquic moisture regime. Bt horizons limit permeability and cause perched water tables. These sites are classified by Cowardin system (Cowardin and others, 1979) as Palustrine, forested, needle leaved evergreen wetlands. Regionally, these sites are very productive, and have been managed as loblolly pine plantations for the past 50 years.

In 1992, three 20 ha, loblolly pine plantations were selected based on similar age, soil, and hydrologic conditions. These

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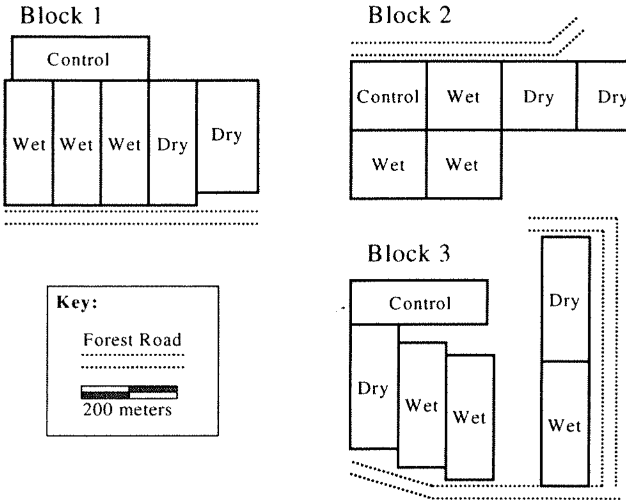

Figure 1—Block design and arrangement of treatments.

plantations (assigned as blocks) were subsequently divided into six 3.2 ha treatment plots (figure 1). Despite being contiguous within each block, each plot was treated as an individual management unit. Harvesting was conducted using conventional commercial logging operations using feller buncher/grapple skidder systems. Each plot was laid out as a separate sale and had separate decks and skid trails. In the fall of 1993, two plots on each block received a dry weather harvesting treatment. In the spring of 1994, the remaining three plots on each block were harvested during wet conditions in order to maximize soil disturbance.

Prior to harvesting, each stand was cruised for height, and diameter. Bole biomass was estimated as a function of height, diameter, and age (Baldwin, 1989). Biomass of crown components (branches and foliage) was estimated as a function of height and diameter. In addition, samples of ground litter were collected and weighed to determine biomass already present on the forest floor.

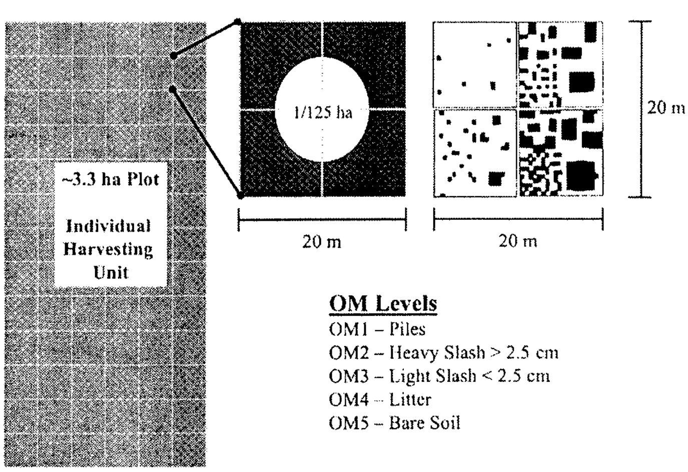

Figure 2— A 20x20 meter grid was established on each 3.3 ha plot. At each gridpoint a 1/235th ha plot was used to inventory aboveground biomass, and visual estimates were made of five classes of logging debris.

After harvesting, each stand was surveyed based on the 20x20 m grid (figure 3). Each grid location was divided into four 10x10 m quadrats in which visual estimates were made of percent cover of harvesting residue and averaged. Harvesting residues were divided into four categories: litter, light slash (<1.5 cm), heavy slash (>1.5 cm), and piles (residue > 0.3 m in depth). Visual estimates were made after a visual calibration to a reference chart (figure 2). In the case of slash piles, the depth of the piles was also measured.

After the visual assessments were completed, a subset of grid points was revisited to relate actual biomass to percent cover. A 2 by 2-m PVC frame was randomly placed in each of the four quadrats and a visual assessment was made for litter, light slash, and heavy slash. The air-dried samples were subsequently collected and weighed *in situ*. Simple linear regression was then used to predict biomass for each category based on percent cover. Regressions and statistical analyses were made at the 5 percent level using SAS procedures (SAS Institute, 1988).

An additional estimate of the biomass in piles was required because we were not able to sample them in a timely way. It was assumed that the maximum biomass of heavy slash was equivalent to the threshold level with a 0.3-m deep pile. The estimate was subsequently multiplied by depth to obtain a biomass estimate for individual slash piles.

RESULTS AND DISCUSSION

Prior to harvesting, the amount and distribution of biomass of the tree components and the litter layer were similar between the two harvesting treatments (table 1). Approximately 46 to 48 kg/m^2 was found aboveground in the form of the stem, branches, and foliage. In addition about 0.55 kg/m^2 was found in the pre-harvest litter layer. These materials had normal distributions, meaning they were heterogeneously spread throughout the site (figure 3).

Forty to sixty-five percent of the variation in post-harvest biomass was explained by our visual cover estimates (figure 4). The method tended to under-estimate biomass relative to that predicted by the Baldwin equations (figure 5); the best approximations were made for the dry harvest sites. Standing water and soil disturbances made wet visual assessments of percent cover difficult, which caused the under-estimates of biomass on the sites that were harvested when wet.

Table 1—Pre-harvest biomass of the wet and dry-harvested plots

Treatment	Aboveground Biomass (& carbon)			Pre-Harvest
	Stem	Branch	Foliage	Litter
	———kg/m (kg-C/ha)———			
Dry	37.63(17.08)a	4.07(1.85)a	1.83(0.83)a	0.53(0.20)a
Wet	42.50(19.30)a	4.28(1.94)a	1.86(0.84)a	0.58(0.21)a

Note: means separations compare the levels within each biomass class only.

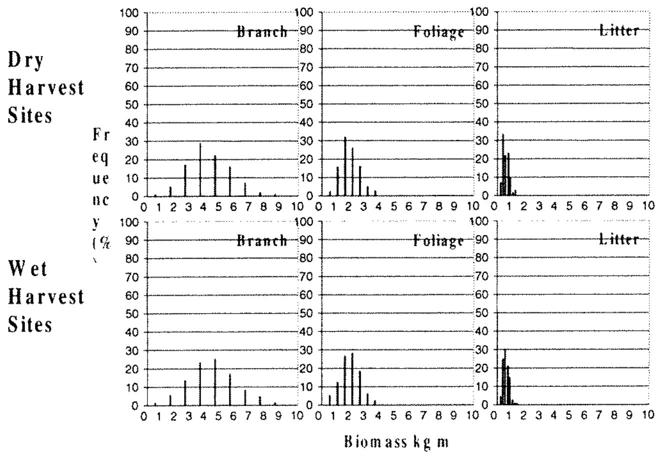

Figure 3—Pre-harvest histograms of coarse organic matter from the standing, live tree (branch and foliage), and on the ground (litter).

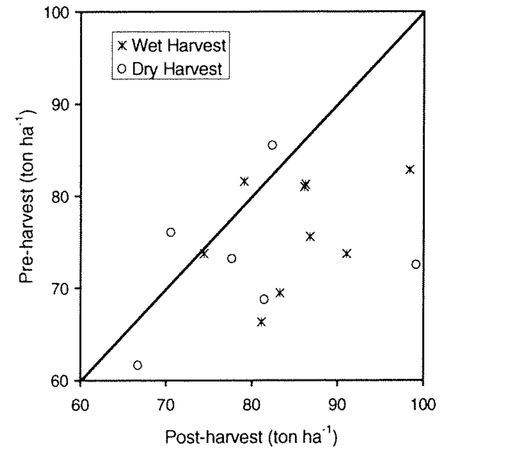

Figure 4—Linear regression plots for the four harvesting debris size classes.

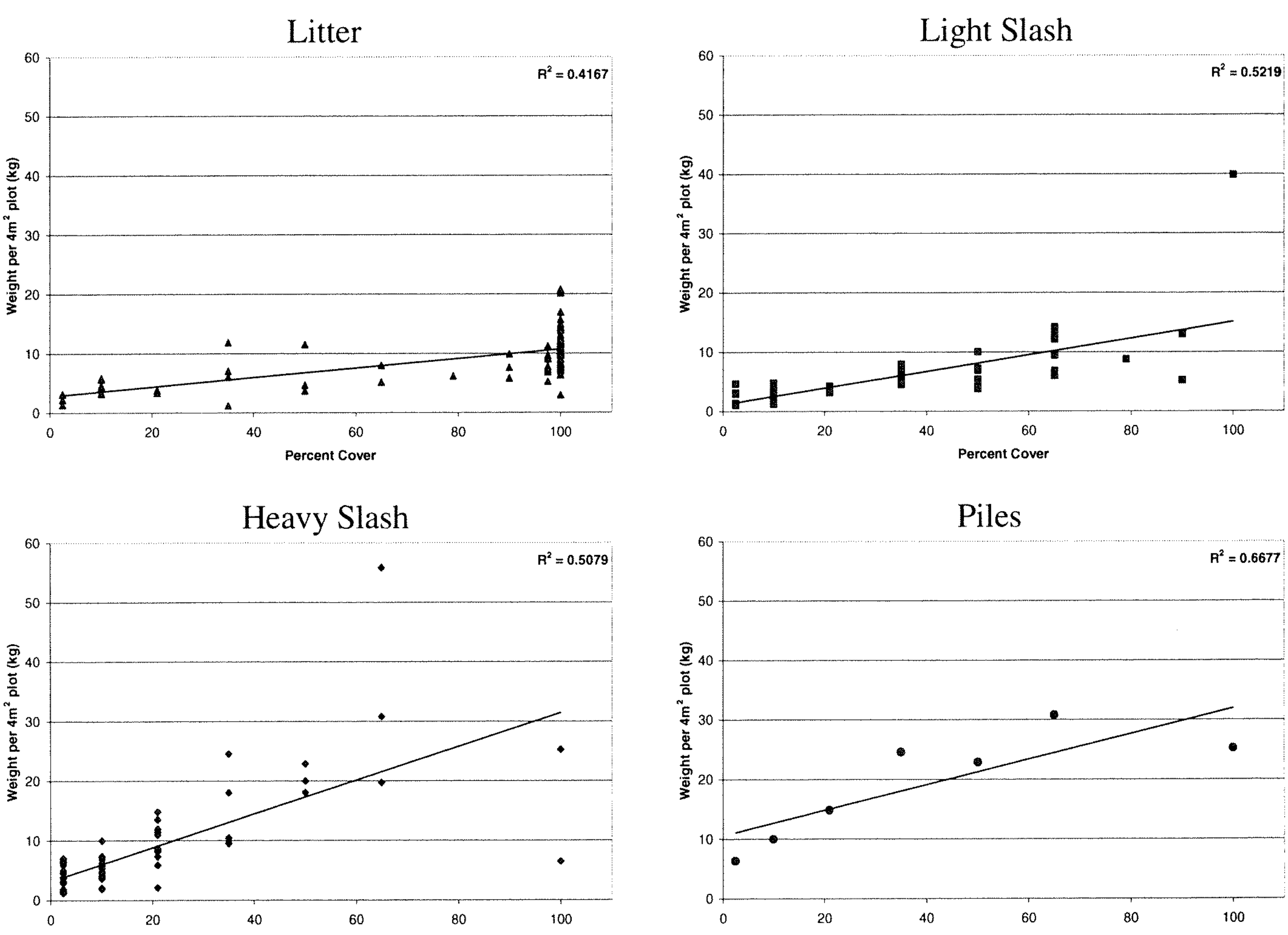

Figure 5—Comparison of pre- and post-harvest total organic matter biomass estimates.

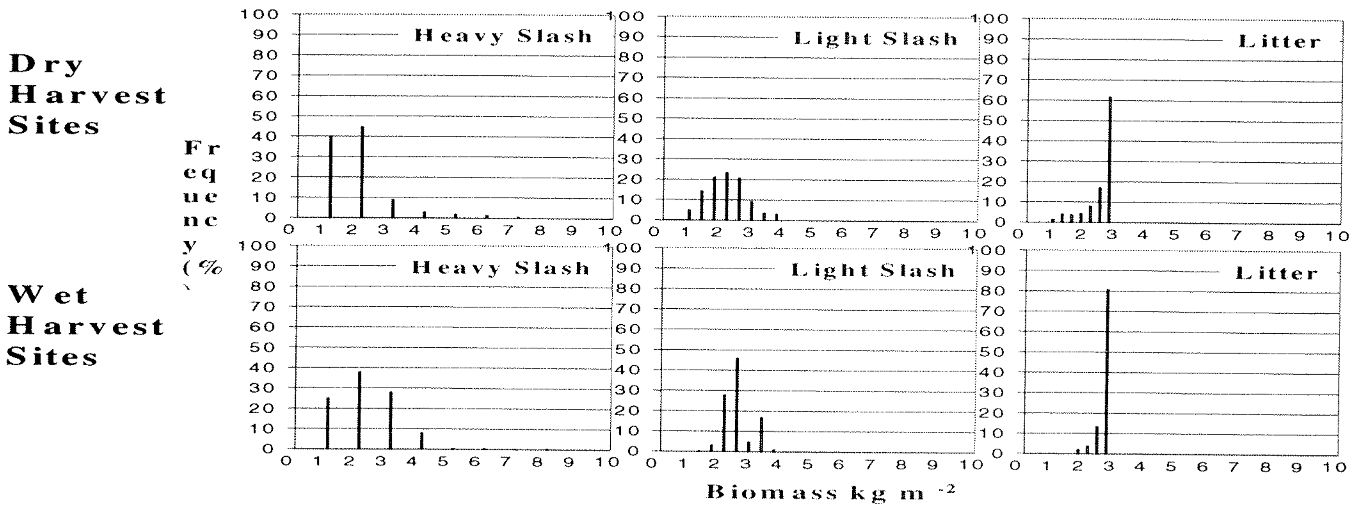

Figure 6—Post-harvest histograms of heavy slash, light slash, and litter.

Table 2—Post-harvest biomass of the wet and dry-harvested plots

Treat-ment Heavy	Slash > 2.5 cm	Light Slash < 2.5 cm	Piles Slash 1 ft deep	Litter
	kg/m (kg-C/ha)			
Dry	1.89(0.86)b	1.99(0.90)b	1.02(0.46)a	2.36(0.87)a
Wet	2.49(1.13)a	2.47(1.12)a	0.16(0.07)a	2.50(0.93)a

Note: means separations compare the levels within each biomass class only.

After harvesting, any biomass that was not removed as product was dispersed as residues across the site. A portion of the ~40 kg m^{-2} of biomass previously contained in the stems along with the 4 kg m^{-2} of biomass from the branches were repartitioned into the post-harvest categories (heavy, light slash, and piles); about 5 kg m^{-2} total for both the wet and dry harvested sites. Foliage biomass from the pre-harvest estimates were combined with the pre-harvest litter layer to form the ~2.5 kg /ha in the post harvest litter layer. Significantly more heavy and light slash was retained within the wet harvested sites (table 2). Dry sites had numerically greater biomass in piles as a result of skidding and delimbing.

Harvesting resulted in a skewed distribution of organic materials compared to pre-harvest conditions (Figure 6).

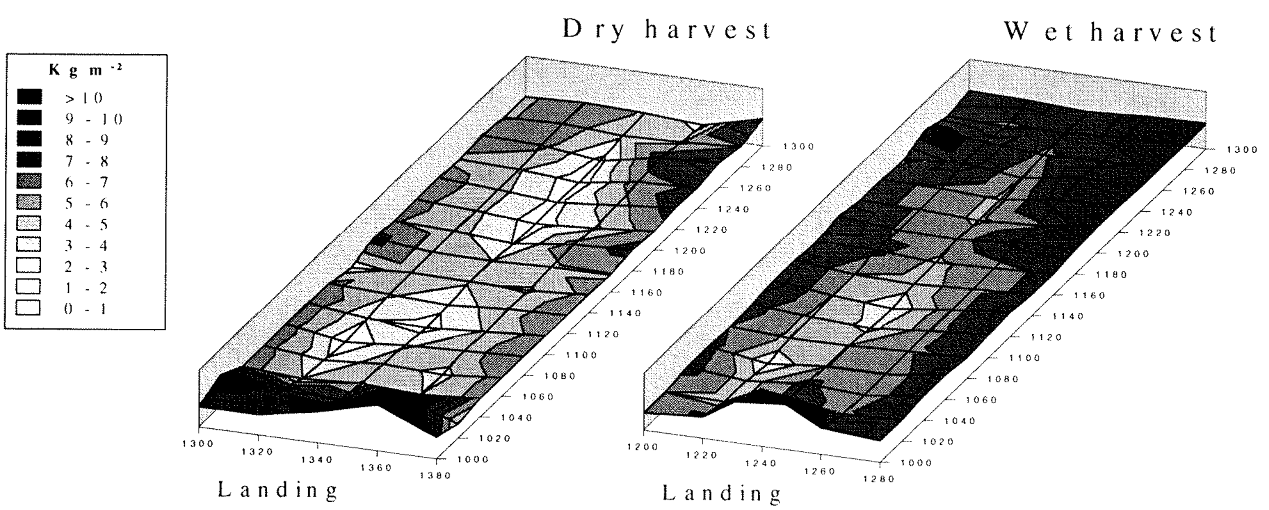

Figure 7—Post-harvest, spatial distribution of organic matter biomass for two treatment plots.

Heavy slash, which would contain components of pre-harvest branch and stem, was left-skewed, indicating that material was being homogenized into many low biomass groupings. Litter on the other hand, which contains components of pre-harvest foliage and litter, was right-skewed, indicating that material was being homogenized into many larger biomass groups.

The displacement of materials by dry-site harvesting is readily apparent in a spatial plot (figure 7). Disturbance of organic materials is minimized around the periphery of a logging site, and it is maximized where traffic is concentrated. In addition, debris are concentrated at the landings of logging sites.

CONCLUSIONS

The visual approach used in this study for estimating harvest residue biomass tends to underestimate the actual amount of residue biomass, especially on the wet-harvested sites. However, this method may be appropriate for the sites with little surface soil disturbance and standing water. Harvesting in general tended to homogenize heavy slash and litter either by skewing their distributions to the left or to the right. Residue materials were displaced to a greater extent within the interior of the plot where trafficking was the highest. At the periphery of the logging site organic materials were less disturbed.

Wet weather harvesting tended to leave a greater amount of organic debris out on the site. Logging operators topped trees where they were cut, and used those materials to support the equipment on the wet soils. As a result, organic materials were incorporated with the soil and may serve to provide a mitigating effect to soil disturbance as time passes (Kelting, 1999).

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DISKING EFFECTS ON FIFTH-YEAR VOLUME PRODUCTION OF FOUR EASTERN COTTONWOOD CLONES ESTABLISHED ON AN AFFORESTATION SITE, SHARKEY COUNTY, MISSISSIPPI

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Abstract—In spring 1995, an eastern cottonwood (*Populus deltoides*) plantation was established on a former agricultural field in Sharkey County, MS to evaluate the effects of clonal variety and mechanical weed control on aboveground biomass production. Four cottonwood clones, ST-66, ST-72, ST-75, and S7C-1 were planted on a 12 foot × 12 foot spacing and subjected to 2 mechanical weed control treatments (disking in year 1 versus disking in year 1 and 2). Survival in the plantation ranged from 96 percent for ST-66 and S7C-1 to 87 percent for ST-72. But, survival was not influenced by mechanical weed control as it averaged 93 percent for each treatment level. After the fifth growing season, mean cottonwood height ranged from 48.3 feet for ST-66 to 39.8 feet for the other three clones. Similarly, diameter of ST-66 averaged 5.5 inches, while diameter of the other clones averaged 4.8 inches. Two years of mechanical weed control did not improve tree growth as heights averaged 41.8 feet and diameters averaged 4.9 inches regardless of disking treatment. Clonal effects on volume production were obvious after 5 growing seasons, ranging from 1038 feet^3 acre^{-1} outside bark for ST-66 to 574 feet^3 acre^{-1} outside bark for ST-75. Volume inside bark ranged from 631 feet^3 acre^{-1} for ST-66 to 279 feet^3 acre^{-1} for ST-75. Multiple years of mechanical weed control did not improve eastern cottonwood volume production five growing seasons after plantation establishment. Results indicate that eastern cottonwood plantations may be established to rapidly develop a forest structure on a wide range of afforestation sites in the Lower Mississippi River Alluvial Valley.

INTRODUCTION

Extensive deforestation in the Lower Mississippi River Alluvial Valley, driven primarily by land use conversion to agricultural production, reduced bottomland hardwood forest acreage by more than 75 percent in the region (Stanturf and others 2000, Sternitzke 1976). Recently, interest in restoring bottomland hardwood forests on marginally economical agricultural land has been spurred by several governmental incentive programs (Stanturf and others 1998). Although most afforestation projects in the Lower Mississippi River Alluvial Valley focus on establishing heavy mast species such as bottomland oaks (*Quercus* spp.) (King and Keeland 1999), some landowners have management objectives that require establishment of fast growing, intensively managed and economically sustainable hardwood plantations (Stanturf and Portwood 1999).

Eastern cottonwood (*Populus deltoides* Bartram ex Marshall), a native, pioneer species that thrives on alluvial soils throughout the central and eastern United States, has several attributes which make it an appealing selection for afforestation in the Lower Mississippi River Alluvial Valley (Cooper 1990). Relative to plantation establishment and development, eastern cottonwood can be propagated with vegetative cuttings, superior clones are available for a variety of site types, plantation cultural practices are well established, it exhibits extremely fast growth rates, and growth and yield models are available for the species (Cao and Durand 1991a, Krinard 1988, McKnight 1970). The suitability of this species to plantation culture has led to its establishment in fiber farms and biofuel plantations worldwide. As an example, more than 3.7 million acres of eastern cottonwood have been planted in China since its introduction in the 1970s (Cao and Conner 1999).

Although sustainable fiber production is often the driving force behind establishment of eastern cottonwood plantations, other environmental benefits can be derived through afforestation with this species. Gardiner and others (In Press) demonstrated that the understory of eastern cottonwood plantations may be suitable for facilitating establishment of other native bottomland tree species on afforestation sites. The importance of eastern cottonwood forests as habitat for game and non-game wildlife species has been established for several decades (Twedt and Portwood 1997, Wesley and others 1981, Wigley and others 1980). Thornton and others (1998) demonstrated that sediment loss in runoff from cottonwood plantations was substantially lower than runoff from fields under conventional

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Table 1—Schedule of operations during establishment of an eastern cottonwood plantation, Sharkey County, MS (adapted from Schweitzer and Stanturf 1999)

Date	Activity
October 1994	- Site preparation: two-pass disking - Row establishment with liquid nitrogen applied in subsoil trenches at 100 pounds $acre^{-1}$
March 1995	- Planted eastern cottonwood cuttings - Herbicide application: 6 foot band application of oxyfluorofen at 80 ounces $acre^{-1}$ + glyphosate at 24 ounces $acre^{-1}$ over dormant cuttings
May 1995	- Mechanical weed control: one-pass disking and row cultivation followed by second pass at right angles 2 weeks later
June - July 1995	- Herbicide application: basal application of oxyfluorofen in a 3 foot band at 32 ounces $acre^{-1}$
August 1995	- Mechanical weed control: one-pass disking and row cultivation followed by second pass at right angles 2 weeks later
Summer 1995	-Pesticide application: carbanyl applied at 16 ounces $acre^{-1}$ for cottonwood leaf beetle control
June 1996	-Pesticide application: carbanyl applied at 16 ounces $acre^{-1}$ for cottonwood leaf beetle control
June - July 1996	- Mechanical weed control: one-pass disking

agricultural production. Vose and others (2000) documented the potential of eastern cottonwood for phytoremediation of groundwater contaminants such as trichloroethylene. Thus, improvements in surface and ground water quality can result from rapid buildup of a litter layer and root system beneath the forest cover. Furthermore, the high productivity of eastern cottonwood makes the species attractive for carbon sequestration and biofuel purposes (Thornton and others 1998, Stanturf and others 2000).

Though cultural practices for establishment and management of eastern cottonwood plantations are well developed, there is a need to refine current management systems. This is particularly relevant to plantation establishment on former agricultural land, sites where eastern cottonwood productivity may be marginal. The purpose of this study was to evaluate effects of clonal variety and mechanical weed control on fifth-year growth and volume production of eastern cottonwood on an afforestation site in the Lower Mississippi River Alluvial Valley.

METHODS

Study Site

The study was conducted on a previously farmed site located in Sharkey County, MS (90° 44' west latitude, 32° 58' north longitude). The site is situated about 1.5 miles east of Anguilla, and immediately north of the Delta National Forest. Soil on the site was mapped as a Sharkey series (very-fine, smectitic, thermic chromic EPIAQUERTS). Annual rainfall in Sharkey County averages 52 inches, and mean temperatures range from 45° Fahrenheit in January to 82° Fahrenheit in July (Scott and Carter 1962). Cultivation of the study site for soybean (*Glycine max* [Linnaeus] Merrill) production ended in the fall of 1994.

Experimental Design

In March 1995, 3, 20-acre stands (blocks) of eastern cottonwood were established using plantation establishment procedures practiced by Crown Vantage, Incorporated (table 1). For each 20-acre stand, 4 cottonwood clones (ST-66, ST-75, ST-72, S7C-1) were planted in 5-acre plots on a 12 foot × 12 foot spacing. Each 5-acre plot was split and randomly assigned a mechanical weed control treatment level. Half of the split-plots received weed control by disking in 1995, and the other half received weed control by disking in 1995 and 1996.

In each split-plot, a 0.5-acre measurement plot was established to record survival, height and diameter growth of eastern cottonwood. Total height and diameter at breast height of surviving cottonwood stems were measured after the fifth growing season. Tree heights were measured to the nearest 0.1 foot with a Criterion 300 Survey Laser (Laser Technology, Incorporated, Englewood, CO 80112), while diameter at breast height was measured to the nearest 0.1 inch with calipers. When multiple stems originated from the same cutting, the largest stem was measured.

Data Analyses

Individual tree volume was calculated using equations developed by Krinard (1988). Total tree volume outside bark = 0.06 + 0.002221 × ($diameter^2$ × height), volume inside bark to a 3-inch top = -0.86 + 0.001904 × ($diameter^2$ × height). If diameter was less than 5.0 inches, equations published by Mohn and Krinard (1971) were substituted. Intercept and slope coefficients from Mohn and Krinard (1971) were 0.21 and 0.00221 for volume outside bark, and -0.62 and 0.00204 for volume inside bark. Volume per acre was calculated by multiplying mean survival for a clone by the mean volume inside bark or outside bark for individual

Table 2—Analysis of variance sketch for a randomized block design with split-plots used to analyze fifth year survival, height, diameter, and volume production of 4 eastern cottonwood clones

Source	Degrees of Freedom
Total	23
Block	2
Cottonwood Clone	3
Error(Cottonwood Clone)	6
Disking	1
Cottonwood Clone X Disking	3
Error	8

stems of the given clone. Basal area per acre was determined in a similar fashion. That is, mean survival for a clone was multiplied by the mean basal area of individual stems of the given clone.

Treatment effects on response variables (survival, height, diameter, volume inside bark, volume outside bark) were analyzed according to a randomized complete block design with split-plots (table 2). The analysis of variance was conducted with SAS statistical software (SAS Institute Incorporated, Cary, NC 27513). Survival percentages were transformed with a square root transformation prior to analysis. Where significant treatment effects were identified ($\alpha = 0.05$), differences between means were calculated according to procedures outlined by Petersen (1985).

RESULTS AND DISCUSSION

Stem-Level

After 5 growing seasons, none of the response variables measured in the eastern cottonwood plantation were influenced by multiple years of mechanical weed control (table 3). Survival was exceptional throughout the plantation, averaging 93 percent for each disking regime. Surviving eastern cottonwood stems averaged 41.8 feet tall and 4.9 inches diameter at breast height. Across disking regimes, stem volume averaged more than 1.4 feet^3 inside bark and 2.6 feet^3 outside bark (table 3).

Table 3—Effects of 1 year and 2 years of weed control by disking on survival, height, diameter, and volume inside bark and outside bark for an eastern cottonwood plantation, 5 years after establishment, Sharkey County, MS

Variable	Disking 1995	Disking 1995-96
Survival (pct)[a,b]	93 ± 1.4 a	93 ± 1.4 a
Height (ft)	41.5 ± 7.2 a	42.2 ± 7.0 a
Diameter (in)	4.9 ± 0.69 a	5.0 ± 0.69 a
Volume inside bark (ft^3)	1.4 ± 0.70 a	1.5 ± 0.88 a
Volume outside bark (ft^3)	2.6 ± 0.97 a	2.7 ± 1.10 a

[a] For each variable, means in rows followed by the same letter are not significantly different at =0.05.
[b] Mean ± standard error.

An early recommendation by McKnight (1970) suggested that eastern cottonwood plantations should be maintained weed-free until they develop to crown closure. More recently, Stanturf and Portwood (1999) suggested that weed control is necessary when stems average less than 6 feet tall after the first growing season, and it is not necessary when stems average greater than 8 feet tall. Benefits of additional weed control are uncertain when first-year stem height ranges between 6 and 8 feet (Stanturf and Portwood 1999). First-year sapling height in this study was on the lower end of the range of uncertainty as it averaged 6.8 feet (data not presented). Our results indicate that the additional year of weed control was not necessary for improving survival or growth of eastern cottonwood. In fact, Schweitzer and Stanturf (1999) reported that third-year growth in the current plantation was reduced by 2 years of mechanical weed control. They attributed the growth reduction to root damage during the second year of disking. Results from this study indicate that factors in addition to tree height should be considered before prescribing weed control practices. Such factors may include competition level and site quality. For example, 6 feet of first-year height growth on a marginally productive soil, such as the Sharkey series in this study, may be comparable to 10 feet of height growth on a highly productive soil such as the Commerce series (Cao and Durand 1991b). Eliminating mechanical weed control in the second year of plantation establishment could amount to savings of 10 dollars per acre.

Clonal effects on survival, height, diameter and volume production were apparent in the plantation by the end of the fifth growing season (table 4). ST-66 and S7C-1 showed 10 percent higher survival than ST-72. Survival of ST-75 was numerically intermediate, but did not differ from the other clones (table 4). On the Sharkey soil series of the study site, ST-66 outperformed all other clones in fifth year height and diameter. Average height of ST-66 was 21 percent taller than the average height of the 3 other clones. Likewise, diameter of ST-66 measured 14 percent higher than the average diameter of the 3 other clones (table 4). As expected, results on volume production by cottonwood clone tracked similar to height and diameter growth. Five years after stand establishment, ST-66 produced a greater stem volume, inside bark and outside bark, than all other clones.

Clonal effects on eastern cottonwood survival and growth are well established (Foster 1985). Results from this study indicate that early growth of ST-66 on a heavy clay soil was superior to the other tested clones. The superior performance of ST-66 would be beneficial on afforestation sites of similar soil where management objectives targeted fiber production, carbon sequestration, or development of vertical structure. However, a thorough consideration of management objectives for the afforestation site should be considered prior to clone selection. To illustrate, Goelz and Monroe (1995) presented findings from a 21-year-old eastern cottonwood clonal trial in the Lower Mississippi River Alluvial Valley. They observed that ST-66 performed well in a short rotation for fiber production, but was only average for the relatively long rotation sawtimber production. Conversely, ST-72, which exhibited average volume production in this study, was a favored sawtimber producer

Table 4—Mean survival, height, diameter, and volume inside bark and outside bark for 4 eastern cottonwood clones, 5 growing seasons after plantation establishment, Sharkey County, MS

	Clone			
Variable	ST-66	S7C-1	ST-72	ST-75
Survival (pct)[a,b]	96 ± 0.58 a	96 ± 1.3 a	87 ± 0.98 b	93 ± 2.0 ab
Height (ft)	48.3 ± 2.1 a	41.8 ± 2.4 b	40.7 ± 2.7 b	36.8 ± 2.4 b
Diameter (in)	5.5 ± 0.21 a	4.8 ± 0.25 b	5.0 ± 0.28 b	4.7 ± 0.26 b
Volume inside bark (ft^3)	2.2 ± 0.36 a	1.3 ± 0.28 b	1.4 ± 0.28 b	1.0 ± 0.17 b
Volume outside bark (ft^3)	3.6 ± 0.42 a	2.5 ± 0.36 bc	2.6 ± 0.38 b	2.0 ± 0.28 c

[a]For each variable means within rows followed by the same letter are not significantly different at =0.05.

[b] Mean ± standard error.

Table 5—Fifth year stem density, basal area and volume outside bark of 4 eastern cottonwood clones planted on a 12 foot × 12 foot spacing at an afforestation site, Sharkey County, MS

Clone	Stem Density (stems/ac)	Basal Area (ft^2/ac)	Volume (ft^3/ac)
ST-66	290	48	1038
S7C-1	290	36	712
ST-72	263	36	680
ST-75	281	34	574

at age 21 (Goelz and Monroe 1995). Additionally, eastern cottonwood productivity can be improved by establishing appropriate clonal mixes (Foster and others 1998). Establishment of extensive, single clone stands where forest restoration objectives are a focus may be inappropriate.

Stand-Level

Estimates of stand development are of primary importance to land managers with forest restoration objectives. Through 5 years of development in the eastern cottonwood plantation, stand density averaged about 280 stems/acre, basal area averaged 38 feet²/acre, and merchantable volume averaged 750 feet³/acre (table 5). In correspondence with individual stem results, variation in stand density, basal area and volume production was observed among clonal stands (table 5). Stem density ranged about 10 percent, basal area ranged about 41 percent, and volume estimates ranged more than 80 percent between clonal stands.

Stand level basal area and volume estimates observed in this study were similar to results reported by Krinard and Kennedy (1980). The study reported by Krinard and Kennedy (1980) involved 4 cottonwood clones established on a former soybean field with soil mapped to the same series as this study. Survival averaged only 75 percent, but the plantation had an average basal area of 38 feet²/acre and yielded a volume outside bark of 683 feet³/acre at year 5. Though the Sharkey soil series is considered marginally productive for eastern cottonwood (McKnight 1970), results from this study confirm the observation of Krinard and Kennedy (1980) that its exceptional growth on these heavy clay soils is unmatched by any other bottomland hardwood species. Eastern cottonwood can be used by afforestation managers to rapidly develop a forest structure on a wide range of site types of the Lower Mississippi River Alluvial Valley.

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SOIL PROFILE CHARACTERISTICS OF A 25-YEAR-OLD WINDROWED LOBLOLLY PINE PLANTATION IN LOUISIANA

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Abstract—Windrowing site preparation, the raking and piling of long rows of logging debris, has been reported to displace surface soil, redistribute nutrients, and reduce volume growth of southern pine forests. Many of these studies have reported short-term results, and there are few long-term studies of the effects of windrowing on soil properties and pine growth. A 16.2 hectare tract on Sacul fine sandy loam (clayey, mixed, thermic Aquic Hapludult) in Jackson Parish in northern Louisiana was windrowed in 1975. The objective of this study is to compare soil physical and chemical properties from scraped areas between windrows with that from windrow pile soils, 25 years after windrowing. Surface, subsurface, and subsoil horizons were sampled from 13 soil profiles within inter-row (scraped) and windrow (piled) positions. Thickness of the O, A, and E horizons, as well as depth to the Bt horizon, were measured in these profiles. Comparisons were made on the following properties for each horizon on each of the two site positions: organic matter, pH, available phosphorus, and exchangeable calcium, magnesium, potassium, and sodium. Bulk density was measured for windrow and inter-row position surface and subsurface soils. Pore space and air-filled volume were calculated using bulk density and water content. Mean bulk density of windrow surface soils was 1.18 g cm^{-3}, as compared with 1.53 g cm^{-3} for inter-row surface soils. Inter-row subsurface bulk density was also significantly greater than that for windrow positions. Inter-row soils at both depths had significantly less pore space and air-filled volume than that of the windrow positions. In contrast to physical properties on the site, there were no significant differences in surface or subsurface soil chemical properties. Site index (base 50 years) of loblolly pine growing between the windrows was the same (97 feet) as that growing on a non-windrowed part of the tract. Although surface and subsurface soils between windrows were significantly compacted, this compaction does not appear to have limited loblolly pine growth. After 25 years, there was little evidence of nutrient redistribution. The effectiveness of windrowing in reducing woody competition during early stand development may be a more important factor influencing growth.

INTRODUCTION

Piling logging slash into elongated windrows is a common site preparation method in the southeastern US. The moving of slash by rakes or blades usually involves displacement of some surface soil. This displacement of surface soil has been associated with redistribution of nitrogen and phosphorus (Pye and Vitousek 1985, Tew and others 1986, Morris and others 1983) and potassium, calcium, and magnesium (Tew and others 1986, Morris and others 1983) away from the bladed or raked area, into the pile. Loss of some of the organic matter enriched surface can result in higher bulk densities, lower porosity and lower hydraulic conductivity (Tuttle and others 1985). Loblolly pine root growth was decreased with small and large increases in bulk density on sand, loam, and clay (Foil and Ralston 1967). Windrowing has been associated with lower volumes in southern pine plantations. Nineteen years after site preparation, a rootraked and windrowed area contained 187 m^3/a of loblolly pine, but a broadcast burned area had a volume of 346 m^3/ha (Haines and others 1975). Across a wide variety of soils in the deep south, Haywood and Burton (1989) found shearing and windrowing to have the lowest loblolly pine site index and volume after 12 years, as compared with five other mechanical site preparation treatments. The soil physical and chemical research on windrows and site preparation is largely focused on the few years after the treatment, with the exception of few studies. Glass (1976) found that the 2.54 cm of displaced surface soil on a 25-year old raked and piled loblolly pine plantation in the North Carolina Piedmont resulted in a 2.5 meter lower site index (50 years) versus adjacent pines in unwindrowed plantations.

The purpose of this paper is to evaluate effects of windrow site position on soil properties of a loblolly pine (*Pinus taeda* L.) plantation in the upper Coastal Plain in northern Louisiana 25 years after windrowing. The study objectives are to evaluate differences in horizon depths, soil physical properties, and soil chemical properties between windrow pile positions and inter-row (cleared) positions.

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Table 1—Soil horizon characteristics of windrow (piled) and inter-row position soils

Variable	Windrow Mean	Windrow SE	Inter-Row Mean	Inter-Row SE	Pr>t
O horizon thickness, cm	2.96	0.42	3.18	0.39	0.7867
A horizon thickness, cm	23.50	4.13	13.65	1.71	0.0251
E horizon thickness, cm	23.50	5.04	14.22	2.65	0.1236
Depth to Bt, cm	46.99	1.94	29.15	2.07	0.0010

Table 2—Soil physical properties of windrow (piled) and inter-row position soils

Variable	Windrow Mean	Windrow SE	Inter-Row Mean	Inter-Row SE	Pr>t
Surface Bulk Density, g cm^{-3}	1.18	0.04	1.53	0.02	0.0001
Surface Pore Space, pct	54.56	1.39	41.19	0.67	0.0000
Surface Air Volume, pct	26.67	1.81	12.57	0.75	0.0001
Subsurface Bulk Density, g cm^{-3}	1.51	0.04	1.67	0.03	0.0061
Subsurface Pore Space, pct	42.01	1.55	35.96	1.21	0.0072
Subsurface Air Volume, pct	11.47	1.14	7.92	0.92	0.0277

METHODS

The study area, a 16.2 hectare tract, is located in Jackson Parish, LA, within the upper coastal plain. The entire tract is mapped as a moderately well drained Sacul fine sandy loam (clayey, mixed, thermic Aquic Hapludult). The tract was sheared and windrowed after harvesting in 1975. The windrows were burned but not planted to pine, and regenerated to hardwoods. Windrow piles are 3 meters wide, 30.5 meters apart, and comprise 10 percent of the tract.

Vegetation and soils were characterized on plots on windrow piles (windrows) and between windrows (inter-rows). Vegetation was measured in 0.0405 hectare rectangular plots on windrows and in two rectangular plots of the same size between windrows. Heights and diameters of pines and diameters of hardwoods were measured. Dominant and co-dominant trees were classified. Site index for loblolly pine was calculated by inputting the dominant and codominant heights into USDA Natural Resource Conservation Service software version (SCS-690) of the site index curves of Schumacher and Coile (1960).

The impact core method was used to sample bulk density. Cores in aluminum cylinders were taken at the surface (0-10 centimeter) and subsurface (10-20 centimeter) depths. Three replicates were sampled at each depth to represent bulk density of a plot. Bulk density was measured for 9 windrow (piled) plots and 9 inter-row plots. All cores were sampled the same day in February, 2000. Cores were weighed in the field-moist state and after oven drying. Pore space and air-filled volume were calculated using these weights.

Soil profiles were described for three windrow locations and ten inter-row locations. Profile locations were located randomly within the tract. Depths, thickness and Munsell colors for the A, E, EB, and BE horizons were measured. Depth to the Bt and thickness of the O horizon was also measured. Texture for each horizon, including the upper Bt, was estimated using the hydrometer method. Each horizon sampled was analyzed by the Louisiana State University Soil Testing Laboratory (Brupbacher and others 1970) for pH (1:1), organic matter (Walkley-Black potassium dichromate oxidation), available phosphorus (Bray 2 ammonium fluoride extraction), and exchangeable (ammonium acetate, pH 7) calcium, magnesium, potassium, and sodium. Phosphorus levels were determined using a spectrometer, and exchangeable cation concentrations were measured using inductively coupled argon plasma emission spectrophotometry (ICP).

Means of windrow position and inter-row soils' horizon thicknesses, physical and chemical properties were compared using the t test procedure in SAS. Equality of variances was tested (F' test), and where the variances were unequal, Satterthwaite's approximate t test was used to test significance (SAS Institute Inc. 1985). Overall significance was determined at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Soil Profiles

Windrow soils had significantly thicker A horizons and deeper depths to the argillic (Bt) horizon (table 1). Transitional horizons such as EB increased depth to the Bt also.

Table 3—Soil chemical properties of A horizons of the windrow (piled) and inter-row position soils

Variable	Windrow Mean	Windrow SE	Inter-Row Mean	Inter-Row SE	Pr>t
pH	5.50	0.21	5.29	0.08	0.2908
Organic Matter, pct	2.23	0.28	2.37	0.30	0.8231
Phosphorus, mg/kg	7.33	0.88	7.30	0.52	0.9756
Calcium, mg/kg	519.00	179.31	338.10	36.36	0.4218
Magnesium, mg/kg	64.00	12.12	64.20	5.39	0.9867
Potassium, mg/kg	31.33	4.67	41.00	3.98	0.2425
Sodium, mg/kg	19.33	0.88	19.80	0.65	0.7245

Table 4—Soil chemical properties of E horizons of the windrow (piled) and inter-row position soils

Variable	Windrow Mean	Windrow SE	Inter-Row Mean	Inter-Row SE	Pr>t
pH	5.30	0.20	5.26	0.10	0.8358
Organic Matter, pct	0.45	0.09	0.64	0.05	0.1085
Phosphorus, mg/kg	4.00	0.58	3.89	0.20	0.8164
Calcium, mg/kg	230.67	62.36	211.00	24.14	0.7226
Magnesium, mg/kg	76.33	8.74	57.67	7.26	0.2045
Potassium, mg/kg	25.33	3.18	23.89	1.05	0.5748
Sodium, mg/kg	18.67	1.20	17.44	0.24	0.4186
Sum of Bases, cmol(+)/kg	1.93	0.38	1.69	0.16	0.5038

Table 5—Soil chemical properties of upper Bt horizons of the windrow (piled) and inter-row position soils

Variable	Windrow Mean	Windrow SE	Inter-Row Mean	Inter-Row SE	Pr>t
pH	4.83	0.03	4.77	0.03	0.2456
Organic Matter, pct	0.48	0.06	0.64	0.04	0.0700
Phosphorus, mg/kg	5.00	0.58	4.80	0.25	0.7217
Calcium, mg/kg	344.33	144.35	260.10	43.77	0.4529
Magnesium, mg/kg	473.67	44.18	389.40	50.81	0.4084
Potassium, mg/kg	129.33	12.00	92.90	5.44	0.0103
Sodium, mg/kg	26.00	2.00	27.40	2.02	0.7279
Sum of Bases, cmol(+)/kg	6.03	0.79	4.84	0.51	0.2742

The O horizon was primarily leaf litter, and did not differ between windrow and inter-row positions. The A, E, and transitional horizons had a sandy loam texture, whereas the Bt horizon was clay or clay loam for all plots.

Physical Properties

Inter-row site soils were significantly denser, had less pore space, and less volume of air than the windrow position soils, both in the surface (0-10 cm) and in the subsurface (10-20 cm) (table 2). Subsurface inter-row soils had a mean bulk density of 1.67 g cm^{-3}. Surface soil removal (7.62 cm) in Alabama Piedmont and Hilly Coastal Plain sites increased bulk density from 1.47 to 1.64 g cm^{-3}, but bulk density decreased to 1.35 g cm^{-3} after three years (Tuttle and others 1985).

Soil Chemistry

There were no significant differences in any of the measured soil chemical properties between windrow and inter-row position A horizon soils (table 3). Calcium content was very variable, particularly on the windrow sites, where one plot had a concentration of 846 mg/kg. There is no evidence of nutrient redistribution. KG bladed surface soils (including Sacul) in southeast Texas had less K, Ca, and Mg than control, chopped, or burned soils (Stransky and others 1985). In that same study, 7 years after harvest and blading, the surface soils had the same amount of organic matter as the chopping treatment. Bladed soils had significantly less Ca, but not significantly less P, K, Mg than chopped or burned soils. Tuttle and others (1985) found that a 7.62 cm surface removal treatment decreased organic matter by over 50 percent with respect to a control, 3 years after removal. In that study, N, P, Ca, Mg, and K were all reduced from control levels three years after surface removal.

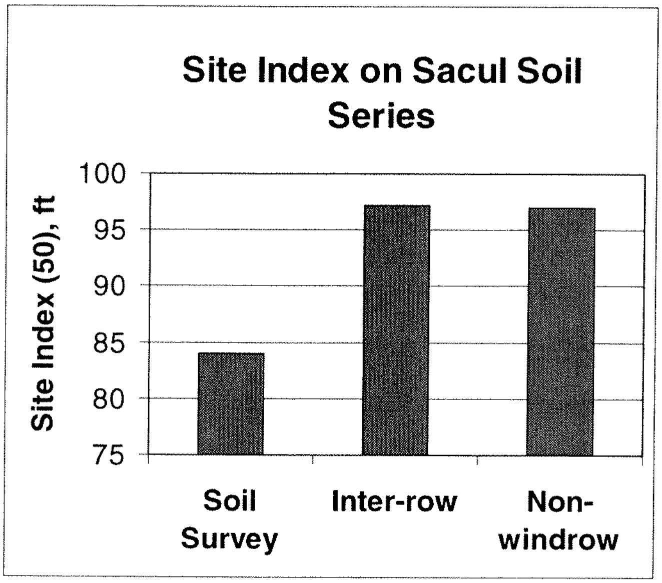

Figure 1—Comparison of loblolly pine site index (base age 50 years) on the Sacul series in Jackson Parish, Louisiana, from Stephens (1999) and measured between windrows and on a non-windrowed area on the study area.

The windrow position E horizons had less (not significant) organic matter than the inter-row sites (table 4). There were no significant differences between site positions for any measured soil chemical property.

The windrow position soils had significantly higher exchangeable potassium levels in the upper Bt, as compared with the inter-row Bt's (table 5). This trend may reflect increased potassium leaching from the slash and through the surface (eluviation), due to increased porosity and infiltration rates in the windrow pile. Potassium could be illuviating in the argillic horizon. Surprisingly, the windrow position Bt horizons contained less organic matter than the inter-row positions had. This trend was also apparent in the overlying E horizons. Prolonged, intense fire in the windrow may have consumed some of the organic matter. Tuttle and others (1983) noted C, Mg, and K appeared to be moving through the upper soil profile 3 years after a surface soil removal.

Overall, there is no evidence in this study for nutrient redistribution from the cleared areas to the piles, or nutrient limitations in the inter-row areas.

Growth of Loblolly Pine

Loblolly pine growing between the windrows had a measured site index of 97.2 feet (figure 1), considerably higher than the published (Soil Survey) figure (using same methods and curve) for the Sacul series in Jackson Parish, LA (Stephens 1999). Loblolly pine on a non-windrowed portion of the tract had a site index of 97.0 feet. The displacement of surface soil and subsequent compaction of the surface and subsurface soil have apparently not severely limited growth of loblolly pine on this site. In contrast to this study, in the Lower Coastal Plain of South Carolina, Fox and others (1989) found that 31 year old loblolly pine between windrows had 10.5 feet lower site index (base age 25 years) as compared with that on non-windrowed sites.

Bulk density in the sandy loam subsurface (10-20 cm) of the inter-row position was 1.67 g cm^{-3} (table 2). Growth limiting bulk density for sandy loam texture is >1.65 g/cm^3 (Daddow and Warrington 1983. Coile and Schumacher (1953) found that 5 cm reduction in surface soil thickness could reduce loblolly pine site index (50 years) by 0.3 to 1.5 m. In the few years following shearing and raking debris into windrows, loblolly pine growth may increase over that of non-windrowed areas. Windrowing, by removing part of the woody competition seed bank and roots, can have a beneficial effect on early pine productivity (Allen and others 1991, Powers and others 1998).

CONCLUSIONS

Twenty-five years after windrowing site preparation, surface and subsurface soils between windrows were significantly compacted, as compared to windrow pile soils. This compaction does not appear to have reduced loblolly pine growth, as compared with growth on an adjacent non-windrowed area . After 25 years, there was little evidence of nutrient redistribution into the windrows. The effectiveness of windrowing in reducing woody competition during early stand development may be a more important factor influencing growth.

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ASSESSMENT OF DOMINANT/CODOMINANT HEIGHT GROWTH FOR SECOND ROTATION SLASH PINE PLANTATIONS IN SOUTH GEORGIA AND NORTH FLORIDA

Charles E. Rose Jr. and Barry D. Shiver[1]

Abstract—A slash pine (*Pinus elliottii* Engelm.) successive rotation plantation study was established in 1978-79 for the north Florida and south Georgia flatwoods. The second rotation duplicated the first rotation seed source, site preparation, planting method, and density. The comparison between the two rotations is based on the mean height differential for the spectrum and by soil type for each age class. There is a significant rotation 1 minus rotation 2 height difference for all age classes. Rotation 1 is 1.9 and 5.4 ft higher for mean height at ages 2 and 20. Rotation 1 generally experienced more favorable precipitation, for both the amount and timing of the precipitation within a year, than rotation 2. Rotation 2 experienced drought events and high temperatures during the first two growing seasons, while rotation 1 was near normal for this period. The evidence suggests that the main contributor to the decrease in height across the spectrum of plots and age classes is the less favorable overall growing season climatic conditions experienced by rotation 2 relative to rotation 1.

INTRODUCTION

Plantation forestry has an enormous economic impact on the southeastern United States. Maintaining or increasing site productivity is an important economic consideration in the Southeastern United States. There have been conflicting reports with respect to successive rotation productivity during the past several decades (e.g. Thomas 1961, Keeves 1966, Boardman 1978, Haywood 1994, Haywood and Tiarks 1995). Zeide (1992) suggested that there is no reliable evidence that pine growth has declined in the southeast. This issue was addressed by implementing a successive rotation productivity study for slash pine (*Pinus elliottii* Engelm.) plantations in the north Florida and south Georgia flatwoods.

The objectives of this study are to compare the productivity and associated climatic data (precipitation and temperature) for the first and second rotations of these north Florida and south Georgia flatwoods slash pine plantations. The productivity comparison is based on the rotation 1 minus rotation 2 (R1-R2) mean height differential for a range of sites and ages. The height differentials are contrasted by soil types and for the spectrum of soil types for ages 2, 5, 8, 11, 14, 17, and 20. The precipitation comparison is based upon the yearly and monthly total precipitation received by each rotation. The climatic data will also be used to assess any drought events and/or extreme temperature fluctuations by rotation.

DATA

Twenty installations were established on non-old-field plantation slash pine sites in the flatwoods of south Georgia and north Florida during the spring of 1978. Each installation consists of 13 0.5-arce-treatment plots with one plot considered the plantation productivity (previous treatment) plot. The other 12 plots at each installation encompass a slash pine site preparation, fertilization, and vegetation control study, and results from these plots have been reported in several publications, e.g., Shiver et al. (1990), Pienaar and Rheney (1993), Pienaar et al. (1996). Five installations were established in each of the following four soil classes:

I) poorly drained non-spodosol,
II) somewhat poorly to moderately drained non-spodosol,
III) poorly to moderately drained spodosol with an underlying argillic horizon; and
IV) poorly to moderately drained spodosol with no underlying argillic horizon.

The site indices (base age 25) ranged from 55 to approximately 80. The previous treatment plot at each installation was designed to replicate, as accurately as possible, the characteristics and preparations of the first rotation for a given installation. The previous treatment plot's seed source, site preparation method, planting method and density replicated those of the first rotation at each installation. Currently only 16 of the original 20 installations remain.

The first rotation was harvested in 1978, and site preparation treatments were applied in 1978-79. The previous treatment plots were hand planted using the first rotation spacing design, which varied by location, during the 1979-80 planting season with 1-0 slash pine seedlings.

First Rotation Data Collection

The following information was collected from the plot randomly chosen to be the "previous treatment" plot at each

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Table 1—The Standardized Precipitation Index (SPI) values and their interpretation (McKee et al. 1993)

SPI value	Interpretation
2.0 and greater	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

location prior to harvesting the first rotation plots in 1978. All trees within the plot were measured for dbh, total height, crown class, and presence or absence of cronartium (*Cronartium fusiforme*, Hedgc. and Hunt). Additionally, six dominant/co-dominant trees were randomly selected from the previous treatment plot for stem analysis, with disks cut at 6 inches above the ground, 5 feet above ground, and thereafter, at 5 foot intervals.

Second Rotation Data Collection

All trees within the 0.2 acre measurement plots were measured for dbh with the crown class and presence or absence of cronartium recorded. Additionally, one-half of the trees were randomly selected for height measurement with the height being measured on these trees at each measurement period. The second rotation previous treatment plots have been measured on a three-year cycle beginning at age 2 and currently measurements are recorded to age 20.

Climate Data

The climate surface data for a given installation were obtained from the National Climatic Data Center (NCDC 2000). The climate data were obtained from the nearest viable weather station for a given plot. A viable weather station was defined as a station containing the monthly precipitation and temperature information for both rotations. Twelve different weather stations were obtained using this selection method. Most of the viable weather stations were within 5-10 miles of the plots, but some weather stations were approximately 25 miles from the plots. The climatic surface data from these weather stations contain the monthly mean temperature and total monthly precipitation.

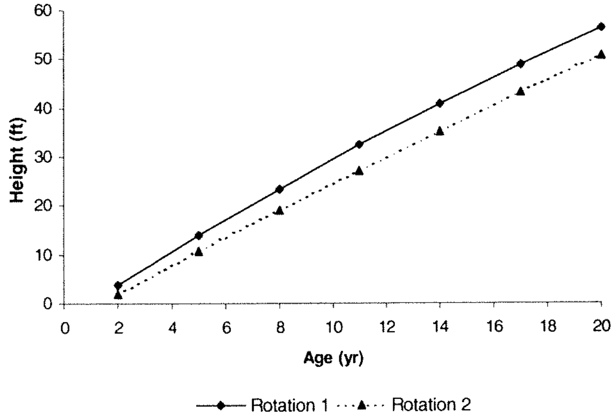

Figure 1—The north Florida and south Georgia slash pine mean

Mean Dominant/Codominant Height Methods

A two-step process was used to assess the height differential between rotations 1 and 2. The first step was to obtain estimates of the mean dominant/codominant heights by rotation and plot for each age class. A mixed model was used to obtain height estimates by rotation and age class for each plot. Secondly, the height point estimates were used to perform an ANOVA by age class. A split-plot model was used to test for rotation height differences. The current data result in an unbalanced split plot model because the replications per soil type are not equal due to the loss of some plots. Soil type was treated as the whole plot and rotation as the split plot. The plots within a soil type were treated as random effects to make inferences across the region. The statistical model used is:

$$H_{ijk} = m + t_i + e_{ij} + b_k + (tb)_{ik} + e_{ijk}.$$

Where H_{ijk} is the mean dominant/codominant height for the j^{th} plot and i^{th} soil type of rotation k,m is the overall mean height,t_i is the i^{th} soil type effect (whole plot),e_{ij} is the whole plot error term (random error on plot j in soil type i),b_k is the rotation effect,$(tb)_{ik}$ is the soil type and rotation interaction effect, and e_{ijk} is the split plot error term (random error for plot j in soil type i and rotation k).

Climatic Data Assessment Methods

An unbalanced split-plot mixed model was used to test for precipitation differences between the rotations. The rotations are treated as the whole plot effect and time is the split-plot effect. The plots within a rotation are treated as random to make region wide inferences. The Standardized Precipitation Index (SPI) and its classification system (table 1) were used to quantify yearly and monthly drought events. McKee et al. (1993) defined a drought event as when the SPI is continuously negative and falls to -1.0 or less. The drought event ends when the SPI becomes positive; therefore the drought event length is defined. The drought magnitude is the sum of the absolute values for all the months or years within a drought period. The average annual and summer temperatures were computed by installation and across the region to assess when or if a rotation experienced extreme temperature fluctuations. The annual and summer temperatures were calculated both as an average for the 16 installations and for each installation individually by rotation.

Dominant/Codominant Height Growth Results

The height estimates for the 16 plots revealed that by age 2, the rotation 1 mean height is substantially higher than rotation 2. The profile plots for both rotations for the spectrum of soil types illustrate that the mean height for rotation 1 is consistently higher than rotation 2 (figure 1). The profile plot exhibits little interaction, which implies that height is an additive effect of rotation and age. The R1-R2 height differential gradually increases across the data range. Profile plots by soil types and soil groups (non-spodosol and spodosol) revealed similar trends.

Table 2—The north Florida and south Georgia first and second rotations slash pine mean dominant/codominant height ANOVA results by age

Source of Variation	NDF*	DDF**	Type III F	Pr > F
<u>Age 2</u>				
Soil	3	12	1.34	0.3083
Rotation	1	12	31.99	0.0001
Soil*Rotation	3	12	1.92	0.1810
<u>Age 5</u>				
Soil	3	12	3.02	0.0719
Rotation	1	12	19.88	0.0008
Soil*Rotation	3	12	0.62	0.6137
<u>Age 8</u>				
Soil	3	12	2.95	0.0757
Rotation	1	12	15.45	0.0020
Soil*Rotation	3	12	0.41	0.7481
<u>Age 11</u>				
Soil	3	12	2.63	0.0982
Rotation	1	12	13.44	0.0032
Soil*Rotation	3	12	0.34	0.7999
<u>Age 14</u>				
Soil	3	12	2.11	0.1517
Rotation	1	12	11.78	0.0050
Soil*Rotation	3	12	0.29	0.8323
<u>Age 17</u>				
Soil	3	12	1.47	0.2724
Rotation	1	12	9.74	0.0089
Soil*Rotation	3	12	0.25	0.8600
<u>Age 20</u>				
Soil	3	12	0.84	0.4983
Rotation	1	12	7.14	0.0204
Soil*Rotation	3	12	0.21	0.8882

* NDF = numerator degrees of freedom.
**DDF = denominator degrees of freedom.

The ANOVA for height by age class revealed that the interaction and main effects tests indicate no significant interaction between soil and rotation (table 2). The soil factor is not significant for all ages (a = 0.05). There is a significant height difference between rotations for all ages, but the significance decreases as age increases. Contrasts for the rotation 1 minus rotation 2 (R1-R2) height differential were constructed and the following is the result synopsis. The contrasts for the R1-R2 pooled height differential are significant for all age classes (a = 0.05). The R1-R2 height differential increases from age 2 to 20, with an average height differential of 5.4 ft by age 20 for the spectrum of plots. The contrasts for the spodosol soil group (soil types III and IV) revealed a significant R1-R2 height differential from ages 2-17, with borderline significance at age 20 (p-value = 0.0518). The spodosols soil group R1-R2 height differential increases to 5.8 ft by age 20. The non-spodosol soil group (soil types I and II) has a significant R1-R2 height differential for ages 2, 5, 8, and 11, and a marginal significant differential for ages 14 and 17 (p-values 0.0532 and 0.0768, respectively). The soil type I contrast revealed no significant R1-R2 height differential for all age classes. Soil type II does have a significant R1-R2 height differential for ages 2, 5, 8, 11, and 14; but the significance decreases so that by age 17, there is only borderline significance (p-value = 0.0693). Soil type III only has a significance R1-R2 height difference at age 2. For soil type IV, there is a significant R1-R2 height difference for the 2-17 age classes and a marginal significance difference at age 20 (p-value = 0.0612). There is an increase in the R1-R2 height differential as a function of age for all soil types except from age 17 to 20 of the soil types II and III.

Table 3—The north Florida and south Georgia first and second rotations slash pine annual precipitation ANOVA results

Source of Variation	NDF*	DDF**	Type III F	Pr > F
Annual Rainfall				
Rotation	1	9.84	2.76	0.1280
Year	19	247	7.61	0.0001
Rotation*Year	19	247	6.91	0.0001

* NDF = numerator degrees of freedom.
**DDF = denominator degrees of freedom.

Climatic Surface Data Results

The ANOVA results for annual precipitation revealed that the interaction between rotation and year is significant (p-value = 0.0001) (table 3). This implies that the amount of annual precipitation for each rotation or year depends upon the level of the other predictor variable. Hence, it is not appropriate to test for rotation main effects across the spectrum of years, but it is appropriate to test for rotation differences by year. The contrasts for testing R1-R2 average annual precipitation differences revealed that rotation 1 received on average, 5.6 and 14.0-inches more precipitation than rotation 2 for the first two years. Rotation 1 had 98 and 104 percent while rotation 2 had 88 and 78 percent of the average precipitation during their first two respective rotation years. Rotation 1 received significantly less rainfall than rotation 2 (8.8 and 9.8-inches) during years 3 and 4, but still had 88 and 97 percent of the average annual precipitation. The years 11 and 12 exhibited the greatest differences with respect to precipitation. Rotation 1 received 19.8 inches more and 11.6 inches less average annual precipitation for these respective years. Rotation 2 received 68 percent of the average annual precipitation for year 11. Although rotation 1 received substantially less precipitation than rotation 2 for year 12, it still received 109 percent of the average annual precipitation.

To compute the SPI index, a square-root transformation was necessary to normalize the precipitation data. The SPI profile plots of the average annual precipitation by rotation reveal that rotation 2 exhibits more variability relative to rotation 1 for the yearly SPI index (figure 2). Rotation 1 experienced one minor drought event (years 3-4) for annual precipitation during the 20 years. Rotation 2 has experienced two previous drought events (years 1-2, and 10-11), and is currently in the third year (1998-2000) of a drought event. Since the height growth decrease for rotation 2 loss relative to rotation 1 was expressed by age 2, the SPI precipitation by month was computed for the initial two years of each rotation (figure 2). The average monthly SPI revealed that rotation 1 did not experience a growing season drought event during the first two growing seasons. Rotation 2 experienced growing season drought events during both of the first two growing seasons.

The temperature data revealed that rotation 2 had below average annual temperatures during the first two years, but during the same period, it had substantially above normal

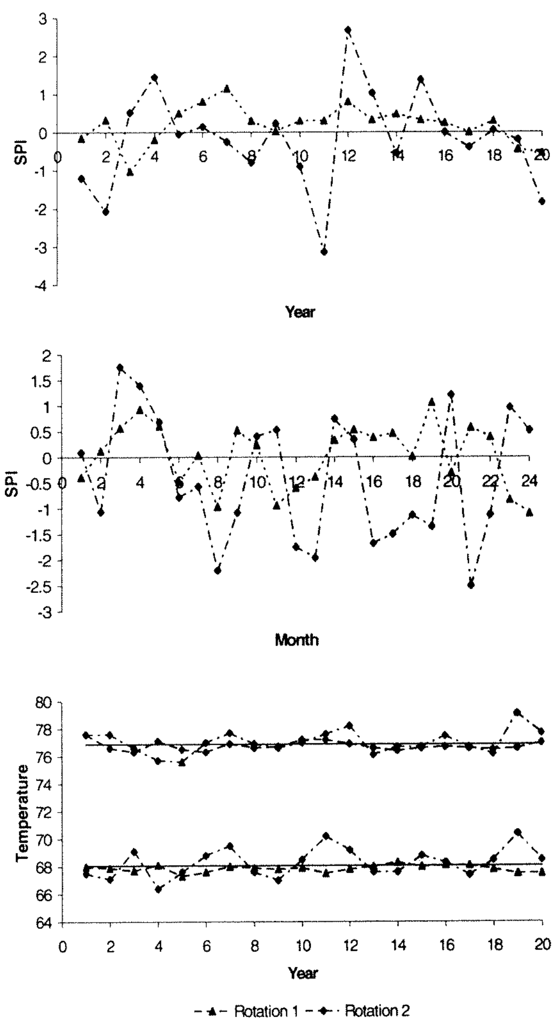

Figure 2—The north Florida and south Georgia slash pine standardized precipitation index (SPI) for mean annual precipitation by year and for the first 24 months (month 1 corresponds to January of the first year). The mean annual and growing season (higher) temperatures by rotation and year. The 69-year weighted average for the growing season and annual temperatures are represented by the solid lines.

temperatures for the growing season (figure 2). Rotation 2 average growing season temperature for the first 2 years was 77.6° F, which is substantially above the average growing season temperature of 76.9° F.

DISCUSSION

The results from the ANOVA for the spectrum of plots by age class revealed a significant height difference between the rotations. Rotation 1 is, on average, 1.9, 3.2, 4.2, 5.0, 5.4, 5.6, and 5.4 feet higher for height than rotation 2 at ages 2, 5, 8, 11, 14, 17, and 20, respectively. The height significance decreases as age increases; but an average R1-R2 height loss of 5.4 feet at age 20 is considerable. The contrasts by soil types don't insinuate any general trend between soil type and the R1-R2 height differential.

It is difficult to quantify competing vegetation or nutrient availability for either rotation because of the lack of data for these factors. The main competitors at most plots for both rotations are gallberry (*Ilex glabra*) and saw palmetto (*Serenoa repens*). There is no indication that the quantity of gallberry and/or saw palmetto has dramatically changed from rotation 1 to rotation 2. The climate data analyses suggest that drought events and warmer growing season temperatures generally correspond with smaller height growth, especially during the first two years. The data revealed that the decrease in height growth experienced by rotation 2 was expressed by age 2. This age 2 height differential corresponds with less favorable growing conditions, on average, experienced by rotation 2 during the first two growing seasons.

The plantation productivity plots used for this study are a separate entity of the study on slash pine site preparation, fertilization, and vegetation control. The goals of the larger study are to evaluate the growth, yield, and stand structure of slash pine plantations using different combinations of site preparation, fertilization, and vegetation control. The site preparation methods used for the productivity study plots were, on average, similar to a chop and burn site preparation. The heights for rotations 1 and 2 were compared with the chop and burn treatment heights. The genetic stock of the first and second rotation productivity plots are different, likely inferior, to the site preparation study plots. The chop and burn plots average heights are 2.7 and 48.8 feet at ages 2 and 20, respectively. The first and second rotation productivity plots mean heights for ages 2 and 20 are 3.4 and 57.1 feet, and 2.1 and 47.0 feet, respectively. This implies that the early rotation climatic conditions have a more profound effect on height growth than genetic stock, for these chop and burn plots.

It is generally accepted that extreme weather temperatures, marginal precipitation, competition, and nutrient deficiency can adversely affect seedling growth. The second rotation, on average, exhibits a height reduction, but the first rotation harvest disturbance is not likely a mitigating factor because management impact was minimized to insure the second rotation duplicated the first rotation as accurately as possible. The main competition for both rotations is gallberry and saw palmetto, but not necessarily at the same densities, therefore competition is not likely the main factor for the mean dominant/codominant height growth loss experienced by rotation 2. Since the genetic stock was the same for both rotations, genetics is not likely the major factor for the height differential between rotations 1 and 2. Because no information is available, a nutrient deficiency can't be eliminated, although it is unlikely, as a major contributor to the R1-R2 height differential. The evidence suggests that the more severe drought events and warmer temperatures experienced by rotation 2, especially during the first two growing seasons, is the main factor for the rotation 2 reduction in height for the spectrum of plots and age classes.

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OAK PLANTINGS AND NATURAL INVASION OF TREE SPECIES ONTO FORMER AGRICULTURAL FIELDS IN THE LOWER MISSISSIPPI RIVER VALLEY

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POSTER SUMMARY

Greater than 80 percent of the bottomland hardwood forests of the Lower Mississippi Alluvial Valley (LMAV) have been lost to conversion over the past 100 years. Of the forests that remain, most are highly fragmented and degraded. Attempts to reforest some of this area over the past 15-20 years have highlighted the need for more information on the relative success of various planting techniques. Controversies still clouds the merits of direct seeding versus planting bare rootstock, and information on broadcast seeding is also lacking. Very little information exists on natural invasion dynamics that are often expected to provide additional tree species and increase diversity. To test a variety of planting methods, the U.S. Fish and Wildlife Service, Louisiana Department of Wildlife and Fisheries, and the Louisiana State University initiated a study during the fall of 1993. Researchers from the Louisiana State University and the U.S. Geological Survey sampled the plots six years later, during the fall of 1999. This poster presented an overall summary of the study. Two additional papers on the study are included in these proceedings and several other manuscripts are planned for future publication (see below).

At each of four locations (Lake Ophelia National Wildlife Refuge [NWR], Tensas River NWR, Bayou Macon Wildlife Management Area [WMA], and Ouachita WMA) 14 treatment combinations were established in a randomized complete block design on 0.4 ha (1-acre) permanent study plots. Treatments consisted of 6 combinations of direct seeding using no till, single disking, double disking, strip disking, and rolling (table 1). Planting was accomplished by using a maximerge planter or a cyclone broadcast planter. Each treatment was further replicated with a fall (1993) and spring (1994) planting. In addition bareroot seedlings were planted by hand and machine during the winter (January/February 1994).

Three oak species were used in the study (table 2); Nuttall oak (*Quercus texana*), water oak (*Q. nigra*), and willow oak (*Q. phellos*). Each treatment was replicated 3 times for each oak species for a total of 84 plots each at Tensas River NWR and Bayou Macon WMA where two species of oaks were planted, and 42 plots each at Lake Ophelia NWR and Ouachita WMA where only one species of oak was planted.

After the 6th growing season (fall 1999) 4 subplots (100 m^2 each, 20 m in toward the center of the main plot from each corner) were sampled in each plot to determine the number and heights of planted oaks and any woody invaders. All tree seedlings/saplings greater than 30 cm tall were identified and categorized by height class (30-50 cm tall, 51-100 cm tall, 101-140 cm tall, greater than 140 cm tall, and greater than 2.5 cm DBH).

Overall, 16,511 seedlings and saplings (greater than 30 cm tall) were recorded in this study. This number included 7,022 planted oaks for an average of 697 oaks and 941 woody invaders per ha. Oak survival was mixed with respect to species and location. Nuttall oak survival was

Table 1—Planting treatments and season of planting

Treatment	Season
Double Disk, Maximerge Direct Seed	Fall, Spring
Double Disk, Maximerge Direct Seed, Roll	Fall, Spring
Strip Disk, Maximerge Direct Seed	Fall, Spring
No-Till, Maximerge Direct Seed	Fall, Spring
Single Disk, Cyclone Broadcast Seed, Single Disk	Fall, Spring
Single Disk, Cyclone Broadcast Seed, Single Disk, Roll	Fall, Spring
Hand Plant Bare Root Seedlings	Winter
Machine Plant Bare Root Seedlings	Winter

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Table 2—Oak species planted at each refuge/wildlife management area

Species	Tensas River NWR	Lake Ophelia NWR	Ouachita WMA	Bayou Macon WMA
Nuttall Oak	X	X		X
Willow Oak			X	X
Water Oak	X			

higher at Bayou Macon WMA and Tensas River NWR compared to Lake Ophelia NWR, while willow oak survival was much better at Ouachita WMA compared with Bayou Macon WMA.

Species composition of the invaders varied significantly by site, probably being affected by the species composition of the adjacent forests. The highest densities were at Bayou Macon where more than 1,200 stems/hectare were recorded. Both Bayou Macon WMA and Tensas River NWR were dominated by 3-4 species (sugarberry, ash and elms) with lesser amounts of several other species. The lowest densities were found at Lake Ophelia NWR, where a broad mixture of species and no overall dominant was found, and at Ouachita WMA where one species, saltbush, dominated.

Planting treatments had significant effects on natural invasion by woody species. Greater numbers of invaders were found on the no-till and strip disk treatments than on treatments that were more thoroughly disked. This effect, however, was caused by the combined responses of the ashes, sugarberry and elms. Invasion rates of most other species were not affected by disking.

OTHER RELATED MANUSCRIPTS PRESENTED AT THE 11TH ANNUAL BSSRC

Michalek, Alexander J., Brian Roy Lockhart, Thomas J. Dean, Bobby D. Keeland and John W. McCoy. 2001. Comparison of hand planting versus machine planting of bottomland red oaks in former agricultural fields in Louisiana's Mississippi Alluvial Plain: Sixth-year results.

McCoy, John W., Bobby D. Keeland, Brian Roy Lockhart, and Thomas J. Dean. 2001. Pre-planting site treatments and natural invasion of tree species onto former agricultural fields at Tensas River National Wildlife Refuge, Louisiana.

ANTICIPATED FUTURE MANUSCRIPTS

Broadcast Seeding in Bottomland Hardwood Reforestation
Spring versus Fall Planting of Red Oaks in the Lower Mississippi Alluvial Valley
Comparison of Planting Bare-Root Seedlings versus Direct Seeding of Bottomland Red Oaks.
No-till, Strip Disking and Double Disking: A Comparison of Effects on Natural Invasion and Red Oak Survival.